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AN APPROACH TO INSTRUMENT TRANSFORMERS

TRAINING BOOKLET: 1

Moving together

INDEX

1. INTRODUCTION

This book is intended to contribute to the training of personnel, especially those who have finished their technical degree and start in a job in which some knowledge about instrument transformers is needed.

The author has used a modern method which summarizes knowledge and links it with actual situations, so that the reader's efforts give him/her a deeper understanding of instrument transformers.

When they were invented in Germany in the 19th century, these machines were simple units covering elementary requirements. A comparison with today's far more complex units shows how far Electrical control and measurement has developed due to the advancement of mathematics, electronics and I.T.

But a product cannot be improved merely through scientific curiosity; other ideas and efforts are also needed. In our company it is the co-operation of all employees, resulting the best product and the best service, as the market and indeed our own prestige demand. Only thus can we achieve our corporate aims.

We hope that this book will provide readers with a better idea of our day to day work, and will raise their determination to improve and increase their knowledge.

2. WHY USE INSTRUMENT TRANSFORMERS?

The electricity consumed in housing, industries, lighting, etc. is generated in large power plants (hydro, thermal, nuclear, wind...) which are usually situated away from the point of consumption. These power stations are linked to consumers via a transmission and distribution grid with a highly complex network. This network is not exclusive to a single electric company or even to a single country; all the power plants and therefore all the consumption points in Europe are inter-connected. At a given time, i.e., a domestic appliance in Sweden could consume electricity generated in southern Spain. To control this energy exchange, measurements must be taken at many points to check the electrical status of each point in the network. In practice, instantaneous vectorial measurements (magnitude and direction) of simultaneous voltage and current reveal the electrical status of points in the system.

In fact, measurements are taken not only at the output of each power plant, and at each point of consumption, but also at the input and output of each of the lines coming together at any transformation and distribution substation. These measurements are taken either for economic reasons or technical reasons. For billing purposes, we must know exactly how much each company is generating and each customer is consuming. To control and manage the grid, we must avoid overloading and we must monitor it in order to detect malfunctions and optimize generation and distribution, making them as economical and safe as possible.

2. WHY USE INSTRUMENT TRANSFORMERS?

Current is measured by inserting the measuring device into the line at the point where measurements are to be taken, so that the full current passing through the line goes through the amperemeter.

Voltage or potential difference is measured by comparing between the point of interest and another point (usually ground potential).

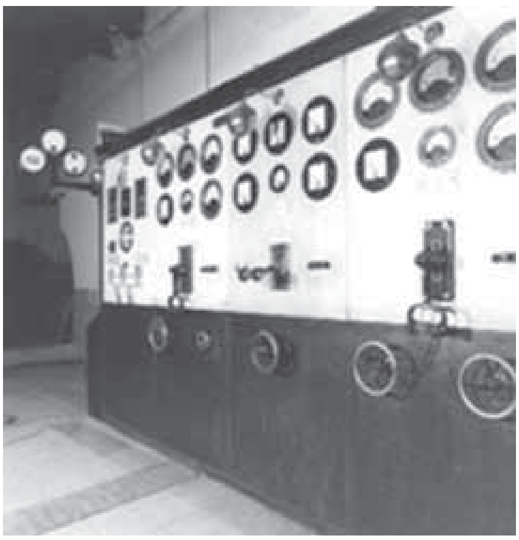
In the early days of electrical development, electrical grids and systems were small and few in number and so measurements to be taken were also few. Therefore, measuring devices were custom built for each application. The grid soon began to increase in size and complexity, making it more and more difficult to manufacture customize measuring equipment for each point to be measured. It is clearly a complicated matter to build an amperemeter that can withstand 100 A, and the same goes for voltmeter rated at up to 10,000 V. Nowadays, currents of 5,000 A and voltages of 800 kV are common in the system.

As electrical networks continued to grow bigger and more complex, measurements were needed at more and more points. A centralized system of control boards became desirable to supervise the whole system. This involved installing many similar measuring devices on the same panel, and it was obvious that the smaller and the more alike they all were, the more economical they would be to install and the easier it would be to monitor the systems they represented.

As mentioned previously, instrument transformers (I.T.s) bring the current and voltage down to a lower but proportional value. These levels are low enough to allow all measuring devices to be built with economical and technologically suitable materials and sizes. These devices are small enough to be fitted into control panels and their current and voltage levels are low enough to avoid danger to personnel while handling, maintenance or commissioning. Furthermore, an agreement on the final voltage and current levels will make measuring devices interchangeable and mass-produced. This makes them cheaper and, since they are all equal, easier to install.

The agreement is, in fact, almost unanimous on this point: almost all V.T.s (voltage transformers) reduce the voltages to 110 or 100 V and C.T.s (current transformers) reduce current to 5 or 1 A.

› Equipment evolution in a control room.



3. WHAT ARE INSTRUMENT TRANSFORMERS?

These are special transformers used for measuring. They are electrical machines which use the electromagnetic properties of alternating currents and ferromagnetic materials to produce voltage and current at different levels from those received as input.

Alternating electric currents create alternating magnetic fluxes which, in turn, can induce other alternating currents in conductors under their influence.

The alternating electric currents flowing through wound conductors create highly concentrated magnetic fields inside the windings.

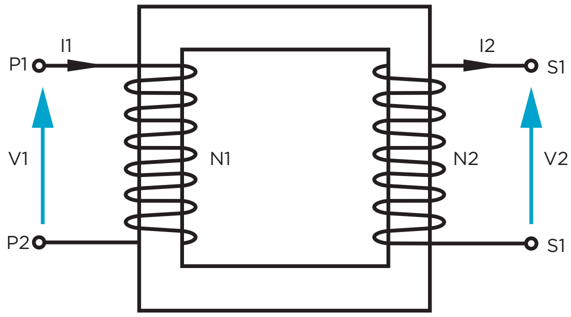
Ferromagnetic materials conduct magnetic flux very well. This property is used in transformers to conduct the magnetic flux generated inside the primary winding, through the core of ferromagnetic material to the secondary winding.

When the magnetic flux passes through the secondary winding it induces an alternating electric current similar to the one that generates the magnetic flux, but somewhat different from it if the windings are not identical.

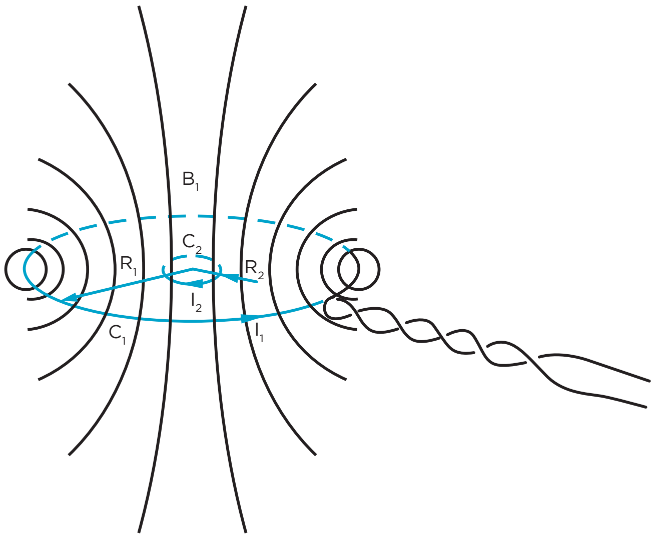
A transformer may be defined as an electric machine that uses electromagnetics to change the electrical characteristics between the input and the output, with a minimum energy loss.

Transformer comprises:

- A primary, which is a winding connected to the power supply.
- A core of ferromagnetic material which links the primary to the secondary, transferring energy from one to the other.
- A secondary, which is a winding connected to the measuring and/or protection devices.



› Transformer schematic diagram.



› Induced current on a turn.

3. WHAT ARE INSTRUMENT TRANSFORMERS?

The difference between primary and secondary makes the electrical characteristics in them different. The main difference is in the number of turns. Transformers are set up so that approximately:

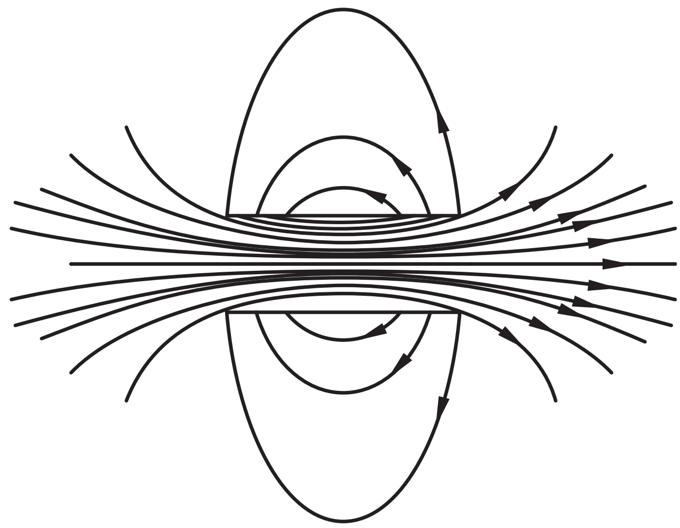
$$\frac{I2}{I1} = \frac{V1}{V2} = \frac{N1}{N2}$$

- I1: Primary current.
- V1: Primary voltage.
- N1: Nr. of turns in primary.
- I2: Secondary current.
- V2: Secondary voltage.
- N2: Nr. of turns in secondary.

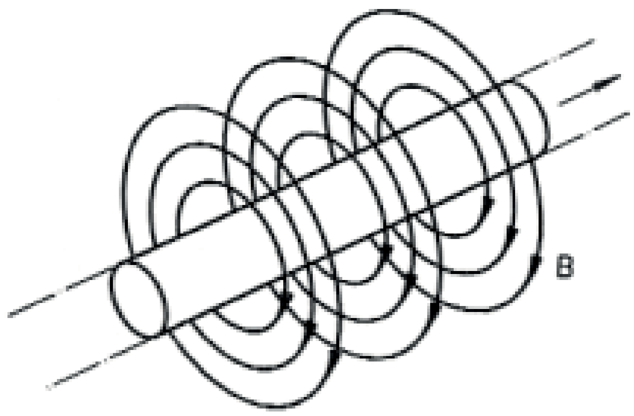
This relation is referred to as the transformation ratio of the transformer.

The feature that distinguishes instrument transformers from other transformers (power transformers, circuit separators, frequency variators, welding transformers, etc.) is the attempt to make the ratio as accurate as possible.

The electrical status of a point in a system is determined by the voltage and current levels measured there and I.T.s (instrument transformers) are design to achieve highly accurate transformation ratios. In C.T.s the ratios is defined between primary and secondary currents, and in V.T.s it is in between primary and secondary voltages.



› Magnetic field created by a cylindrical winding.



› Magnetic field created by a longitudinal lead.

4. COMPONENT PARTS OF INSTRUMENT TRANSFORMERS

This section looks at the components of an actual I.T. and how they are designed and built to overcome the specific problems involved in each of them.

We shall distinguish between the primary, secondary and core, each influences to the electrical and magnetic fields, and the need to isolate them.

4.1. PRIMARY & SECONDARY ELECTRICAL CIRCUITS

The primary and secondary circuits are windings made up of a good electrical conductor. The two best industrial conductors are silver and copper, and since silver is the most expensive, copper is the most widely used. In particular, annealed copper is used, because it is more ductile, and therefore, easier to work with. Aluminum is also a good conductor, though almost two times less efficient than copper. However, it is lighter and considerably cheaper, thus competing with copper in some applications.

Windings must be made of a good conductor, because they have to carry electricity with the less possible losses.

The winding terminals in contact with the atmosphere are usually made of copper alloys such as bronze or brass, pure copper or aluminum. Other metal blends are also used though less frequently.

› Secondary windings for current transformers.

4.2. MAGNETIC CIRCUIT: THE CORE

We have seen that an alternating electrical current creates an alternating magnetic flux. This flux always forms closed lines through space but flows easier through some materials than others. The materials through which it passes easiest are known as ferromagnetic materials (because iron is one of them). As an example, a magnetic flux flow through iron 1,000 times easier than through air.

The purpose of an I.T.s is that all the magnetic flux generated by the primary passes through the secondary to induce in it a current or voltage similar to the one in the primary. Therefore, the secondary is tightly wound around the core allowing the magnetic flux to flow through it.

The magnetic flux circulation through the core produces losses due to the electric energy consumed in magnetizing and heating the core. It is important to minimize these losses, we can achieve that by:

- Using a ferromagnetic material suitable for the desired characteristics, e.g. iron with a 70% nickel content (Mumetal), oriented grain plates, etc.
- Heat treated plates e.g. cold rolling and subsequent annealing.
- Using stacks of very thin plates electrically insulated from each other to eliminate the electric currents induced by the magnetic flux itself, (iron is an electrical conductor, around four times less efficient than copper).
- Eliminating gaps and discontinuities such as bolts when the core is manufactured and assembled.

Cores of different sizes are used according to the power that the primary is to transmit electromagnetically to the secondary. The greater the power, the larger the magnetic flux created and the more iron that flux will use as a roadway. Like any roadway, the core has its optimum level of use: if the flow is too small, the core is underused, and if it is too large, it is saturated.

Core saturation can be compared to a traffic jam on an expressway: the number of vehicles which can pass in any given period depends on the road width (i.e. whether one, two, three or more vehicles can travel parallel to each other) and on the speed at which these vehicles move.

The equivalent to road width in the core is the cross section of the iron through which the magnetic flux passes, and the speed may be the number of ampere turns (A.T.) established. As their name indicates, ampere-turns are the product of the number of amperes circulating through the conductor windings and the number of turns in those windings. Ampere turns indicate the size of the flow created, and those on the primary and on the secondary are equal; the former create the magnetic flux and the latter are generated by it.

› Magnetic core for voltage transformers.

4.3. INSULATION

Fencing and separations on an expressway prevent vehicles travelling in one direction from taking the space reserved for those travelling in the other, and barriers prevent traffic entering unexpectedly on the expressway. Like in all transformers, instrument transformers must have every conductor conveniently insulated from adjacent components and from the outside.

On both the primary and secondary windings the turns must be insulated so that current passes through them one after the other, and not all at the same time. If the wire has a continuous coating of insulating enamel there is one layer of insulation between turns already. This is reinforced with various successive layers of paper. If the wire is not previously insulated it must be insulated in the same way as bare plates and strips are, i.e. with sheaths or cardboard covers. Paper impregnated with insulating gas (usually SF_6) or oil provides far better insulation than paper alone. The impregnation method must be taken into account at design stage.

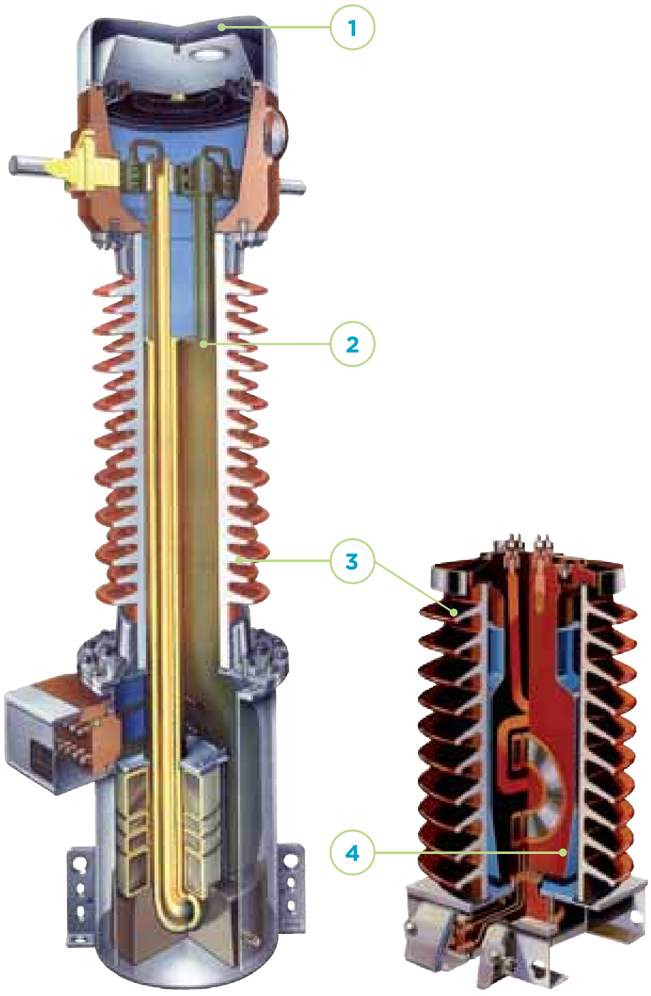
To insulate one winding from another or to insulate the core from each winding, impregnated paper or resin (only up to medium voltage) can be used.

The IT is insulated from the outside by porcelain, silicone or cycloaliphatic resin (only up to medium voltage) for outdoor service units and epoxy resin for indoor service units.

The thin plates that make up the core are also insulated, to prevent it from working as if it were another secondary. This is because the core's material is not only a good conductor of magnetic flux (which is good) but also a fair electrical conductor (not desirable).

Insulation between the core plate cuts off the electric currents generated in them by the magnetic flux and keeps those currents at a very low level (Foucault loss). These plates are insulated by a surface coating applied by their manufacturers.

The type of insulation required depends in each case on many factors, the most important of them is the voltage between the two ends to be insulated. The relationship between insulation thickness and voltage applied is not linear, so it cannot be assumed that twice the voltage requires twice the insulation thickness. Instead, the nature of the dielectric material (insulator) must be considered in each case (dielectric material is a very poor conductor, which means it behaves as an insulator).



1. Oil volume compensating system
2. Oil-paper
3. Insulation between H.V. and L.V.
4. External insulator (porcelain or silicone rubber)
5. Resin insulation

› Models CH and CX.

5. MANUFACTURING AND CLASSIFICATION OF INSTRUMENT TRANSFORMERS

Let us now look at how the general principles laid out in the earlier chapters are applied to several actual cases.

These cases are classified according to distinguishing features or performance characteristics under three main headings: the type of measurement to be made (current or voltage), the location of the device (indoor or outdoor) and the voltage in the grid where it is to be connected (low, medium or high).

The relative importance of certain characteristics and the materials and processes used to make devices vary from case to case.

› Current and inductive voltage transformers of 420 kV. Red Eléctrica de España.

5.1. MANUFACTURING

CURRENT TRANSFORMERS (C.T.)

Current transformers are inserted into the line so that the full current passes through their primaries. They always have two primary terminals with a very small electrical resistance between them, so that, under normal conditions, the potential difference between them is just a few mV and therefore insignificant.

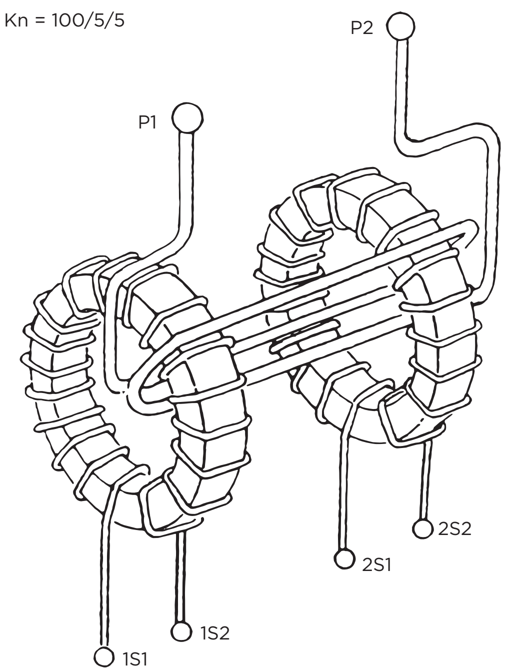
The primary conductor may pass once or more times through the core, depending on whether the current through it is large enough to magnetize the core properly, i.e. whether there are enough ampere-turns. If it is not, extra-turns must be added to the primary to increase the ampere-turns carried.

If a single turn is enough, the primary is usually made of a single copper or aluminium conductor bar. When several turns are required, each one is insulated from the others with a few mm of paper or cardboard.

We always try to make the ferromagnetic core fit the primary as snugly as possible so that the generated magnetic field can be used as much as possible. However, the current driven through the primary is sometimes enough to magnetize the core even when there is some gap.

In these cases C.T.s are made with what we call a “fixed straight bar”, leaving a central hole large enough for the conductor bar to pass through the core easily. If the primary current is not so big, the C.T. is made with a single turn (i.e. with the primary passing only once through the core) but the core is made to fit as snugly as possible against the primary. They are referred to as “incorporated bar” C.T.s, and the line is attached to its terminals. A C.T. with a wound primary looks the same as the above mentioned units, but the primary conductor goes more than once around the core.

C.T. cores are manufactured by simply rolling fine, continuous plate into a torus shape of the required cross section. This plate is supplied with an insulating coating. This is the best way of stacking it tightly so that it forms an even whole with no gaps or insertions of foreign particles. The fact that in normal C.T.s the number of turns is no more than a few hundred, means that direct winding on a closed toroid core is possible with a reasonable expense. (It is cheaper to wind on a mandrel, but in that case the core must be opened to be mounted). The toroid core is padded and insulated with cardboard and masking tape, generally to 4 kV, and the secondary is wound



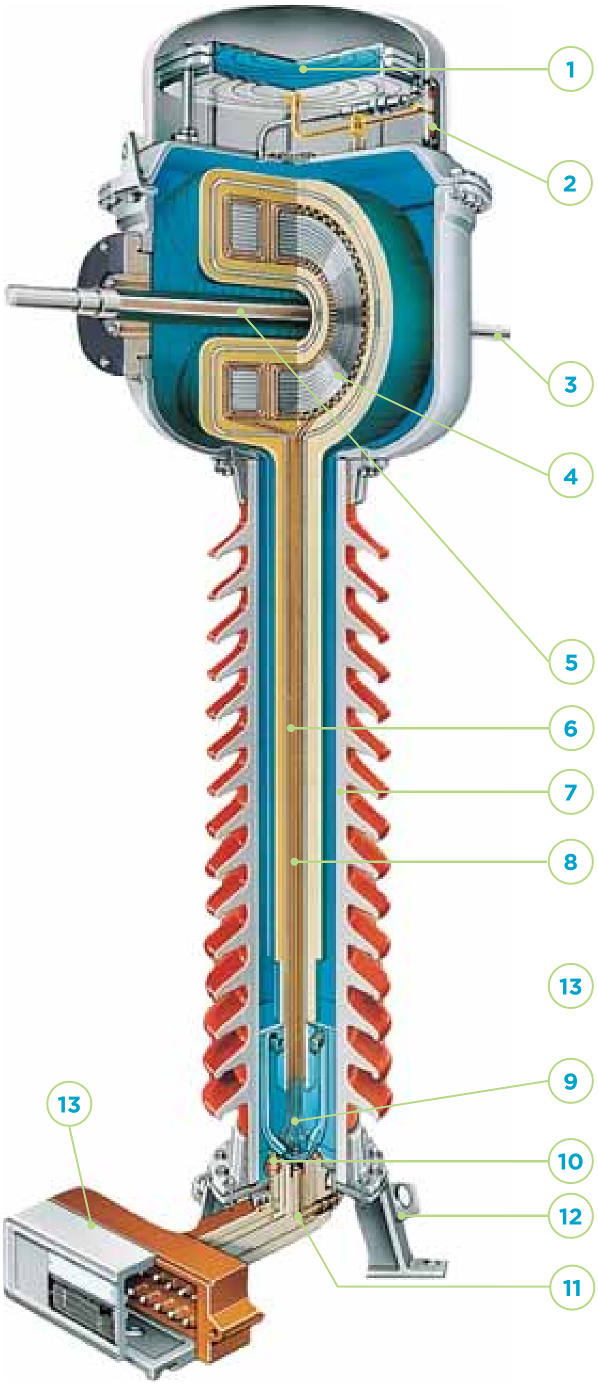
› Core winding process.

› Current transformer.

around, as evenly distributed as possible around the circumference.
It is common to fit more than one secondary if there is enough room. The total number of toroid cores with their secondary windings are manufactured and set along each other with their holes lined up and crossed by the same primary.

In order to simplify insulation of high voltage C.T.s between the primary and the secondary, the cores with their secondary windings are completely sealed in an aluminium box whose shape is carefully designed to correct the electric field. This means that the same insulation design can be used in all C.T.s of the same model, even if the number and size of the secondaries are different.

Sometimes future expansion of a facility, involving a change of current, is foreseen. To avoid having to fit new C.T.s for the new current, C.T.s with several rated primary currents are often requested. This is also done, especially in H.V., so that all the C.T.s in a substation are the same, thus making them easier to replace and maintain, even when each one transforms different current. This is phisically done by means of taps on the secondary windings (with the disadvantage that the number of A.T. (Ampere-turns) is different on each one), or by making the primary in two or four equal windings. When connected in series or parallel; they provide a double primary ratio (D.P.R.) or, in the case of four connected in series/parallel, a triple primary ratio (T.P.R.). The latter system maintains a constant number of A.T. in each connection, but is more expensive due to the larger quantity of copper required in the primary to establish the connections.



1. Oil volume compensating system
2. Oil level indicator
3. Primary terminal
4. Cores and secondary windings
5. Primary winding
6. Secondary conductors
7. Insulator (porcelain or silicone rubber)
8. Capacitive bushing
9. Reinforced ground connection
10. Oil sampling valve
11. Tangent delta tap
12. Grounding terminal
13. Secondary terminal box

› Model CA.

INDUCTIVE VOLTAGE TRANSFORMERS (I.V.T./P.T./M.V.T.)

Voltage transformers are connected between two points with different potential. There is a difference if these two points have different potential from earth or if one of them is directly earthen. The former is known as phase-to-phase type and the latter single phase or phase-to-ground. From the electrical and manufacturing points of view, single-phase V.T.s are a more rational option. However, certain 3-phase measurements can be made more easily using two phase-to-phase V.T.s instead of three single-phase VT. However it is not very common to find phase-to-phase V.T.s above 52 kV.

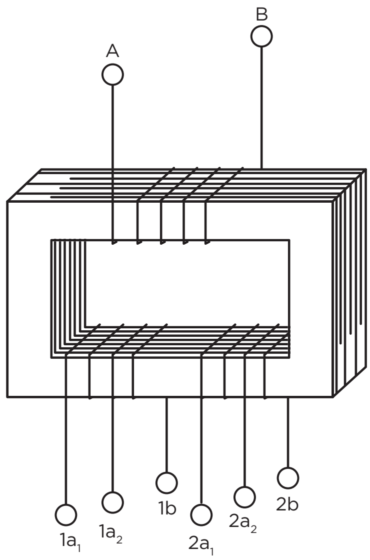
V.T.s usually have a single core on which one primary and one, two or three secondaries are tightly wound. The secondaries have a few hundreds of turns and with just hundreds of volts between their ends. This means that it is enough insulation with the enamel coating of the wires between the turns of a layer and a few tenths of millimeters of paper between layers. V.T.s must be insulated at 3 or 4 kV between secondaries and between each secondary and earth. For this, around 1mm of paper is needed.

Single-phase V.T. have the core and one of the ends of each winding, as well as all the rest of metallic parts of the device connected to earth.

Phase-to-phase V.T.s have their primary terminals insulated from each other at the rated voltage (i.e. the line to line voltage or voltage between phases in the grid). The end of the primary winding is insulated from earth at the rated voltage divided by √3 (phase voltage of the grid). Then, to make the best use of the insulation system, the primary winding is sometimes divided into two symmetrical sections.

The end of each section is insulated at half the rated voltage of the device, with the connection point between them at half the rated voltage level.

The V.T.s cores are rectangular with two columns and sometimes, due to the lack of space, they are armoured. The plates for each side of the rectangle are cut separately and assembled later with threaded bolts. The electromagnetic characteristics of these cores are lower than those of the toroidal cores used in the current transformers (C.T.s), due to the air gaps and insertions between their plates.



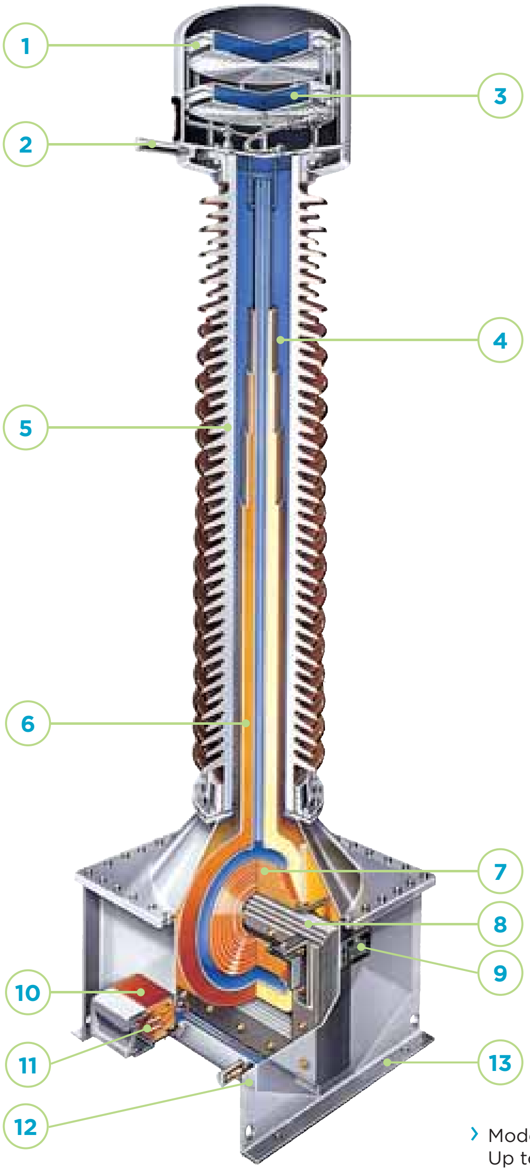
› Voltage transformer.

› Single-phase and phase-to-phase voltage transformers.

5. MANUFACTURING AND CLASSIFICATION OF INSTRUMENT TRANSFORMERS

Nevertheless, rectangular cores are preferred, due to the large number of turns necessary in the V.T.s' primary windings, although this makes the devices larger. Due to the large number of turns, high-speed straight winding machines have to be used in order to wind the wires on a cylindrical mandrel. The primary must now be inserted into the core, and therefore the core has to be opened.

If V.T.s with several primary voltages are required (for the same reasons as the indicated for the C.T.s), these are obtained by means of secondary taps. The reason is that it is cheaper than taking a connection at an intermediate primary voltage even though a higher model of V.T. is required.



1. Oil level indicator
2. Primary terminal
3. Oil volume compensating system
4. Capacitive bushing
5. Oil-paper insulation
6. Insulator (porcelain or silicone rubber)
7. Primary windings
8. Secondary windings
9. Core
10. Tangent delta measuring tap
11. Secondary terminal box
12. Oil sampling valve
13. Grounding terminal

› Model UT.
Up to 300 kV.

CAPACITIVE VOLTAGE TRANSFORMERS (C.V.T.)

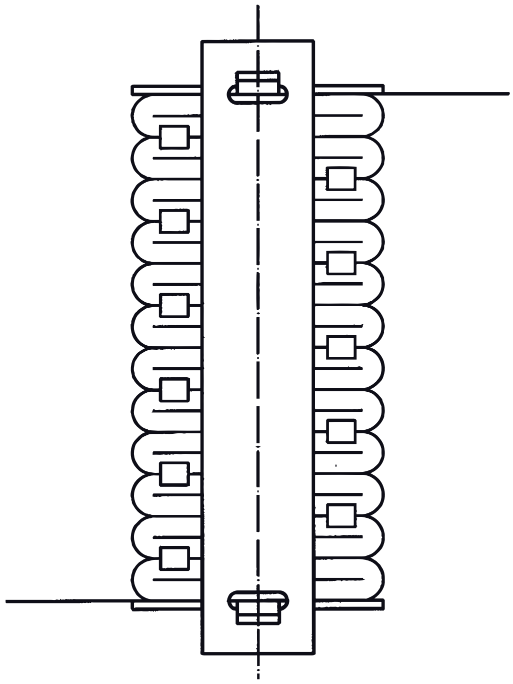
In the inductive voltage transformers considered in the previous section, the number of turns required is higher as the rated voltage increases. This means that the manufacturing process takes longer and is more expensive, windings need more space, and therefore the transformers are bigger.

The electromagnetic technology is not the only way of reducing the voltage to a lower and proportional level. If several capacitors are connected in series and a certain voltage is applied between the first and the last capacitor, each one will be charged at a partial voltage proportional to its capacity. Obviously adding all the partial voltages, we will obtain the total voltage.

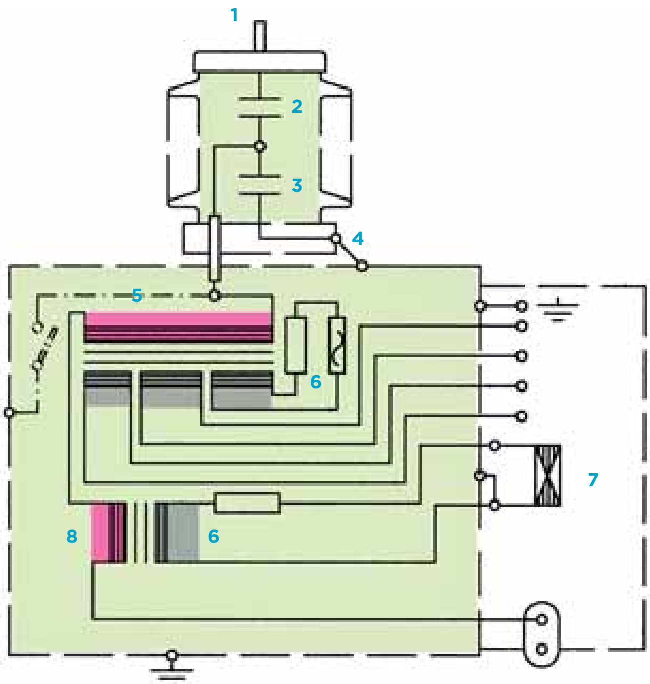
If all the capacitors are the same, the capacitance and the partial voltages will also be equal. The potential difference between any two points in the series of capacitors will be proportional to the number of capacitors between those two points. This introduces the concept of a capacitive voltage divider. The C.V.T. is a voltage transformer with a column of capacitors that has an intermediate voltage tap, that is to say, a capacitive voltage divider, and an inductive voltage transformer connected to that tap. This tap is set at a voltage that allows an inexpensive inductive V.T. to be used (i.e. 22/√3 kV) so that the inductive V.T. is a standard medium voltage model.

The capacitor column must be very carefully manufactured in terms of materials used and the atmosphere of the process. However, this process is simple and repetitive: It begins with the winding of two thin conducting layers of aluminium on a cylindrical mandrel separated by some layers of paper and/or plastic until the length required is reached according to the capacitance desired. This wafer is then pressed and several of them are grouped are packed together and held to maintain their size. The size of the packages must fit the intermediate voltage so that the devices have a whole number of packages.

The capacitor packages have a square section and are fitted in the porcelain shell. Once the unit is dried and the vacuum is done, it is filled with oil. Changes in oil volume due to the temperature variations are neutralized by means of stainless steel cylindrical compensators. Each porcelain forms a separate unit that can be assembled with other units of the same type, for very high voltages, and with the inductive V.T. that is fitted in a metal tank that provides the base for the capacitive voltage divider.



› Capacitor stack.



1. Primary terminal
2. Capacitors
3. Capacitors
4. High frequency terminal
5. Inductive voltage transformer
6. Ferroresonance suppression circuit
7. Secondary terminal box
8. Compensating reactor

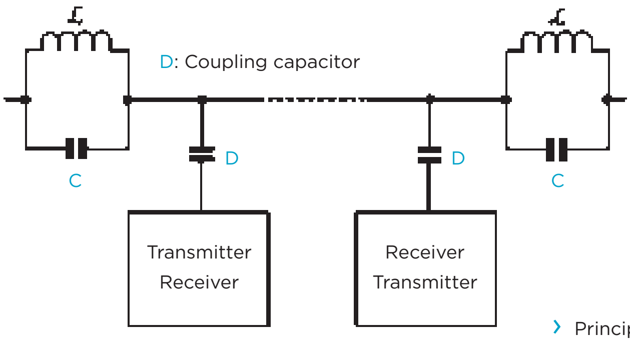
5. MANUFACTURING AND CLASSIFICATION OF INSTRUMENT TRANSFORMERS

Another reason to use C.V.T.s are the telecommunication needs between substations. Electrical networks link points far away from each other: power plants, distribution substations, control centers and consumption points. It is necessary to transmit and receive information from and to these points. The power transmission cables have been always used to carry high frequency telecommunication signals for such essential communication purposes. Apart from this, standard telephone networks, microwave, radio and fiber optic links are also used.

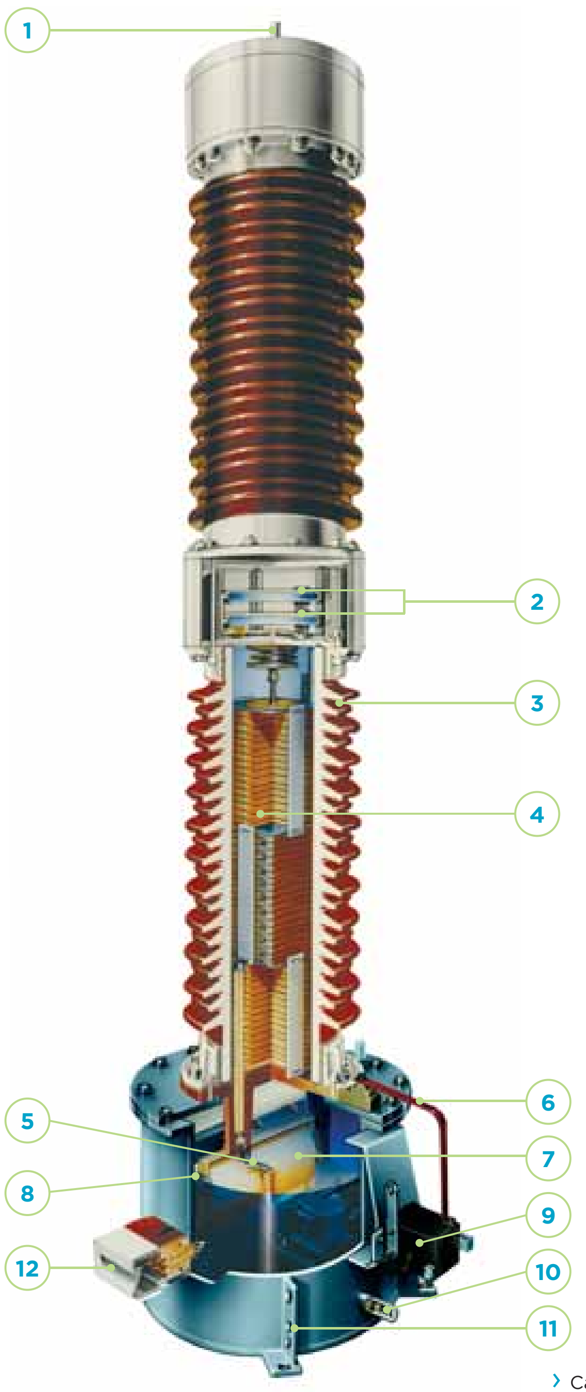
To transmit H.F. signals (40-500 kHz) along 50 Hz HV power line, a H.F. signal input must be made, preventing the loss of electric power. This is achieved by a coupling capacitor with high impedance at 50 Hz and low impedance at more than 40 kHz.

After analyzing all these factors, it was concluded that combining the capacitor voltage divider and the coupling capacitor in the same unit would have important economic advantages.

This C.V.T.s are cost-effective even when used only as transformers. Therefore the H.F. carrier accessories are optional in our transformers.



› Principle scheme of the insertion of line traps in a high voltage line.



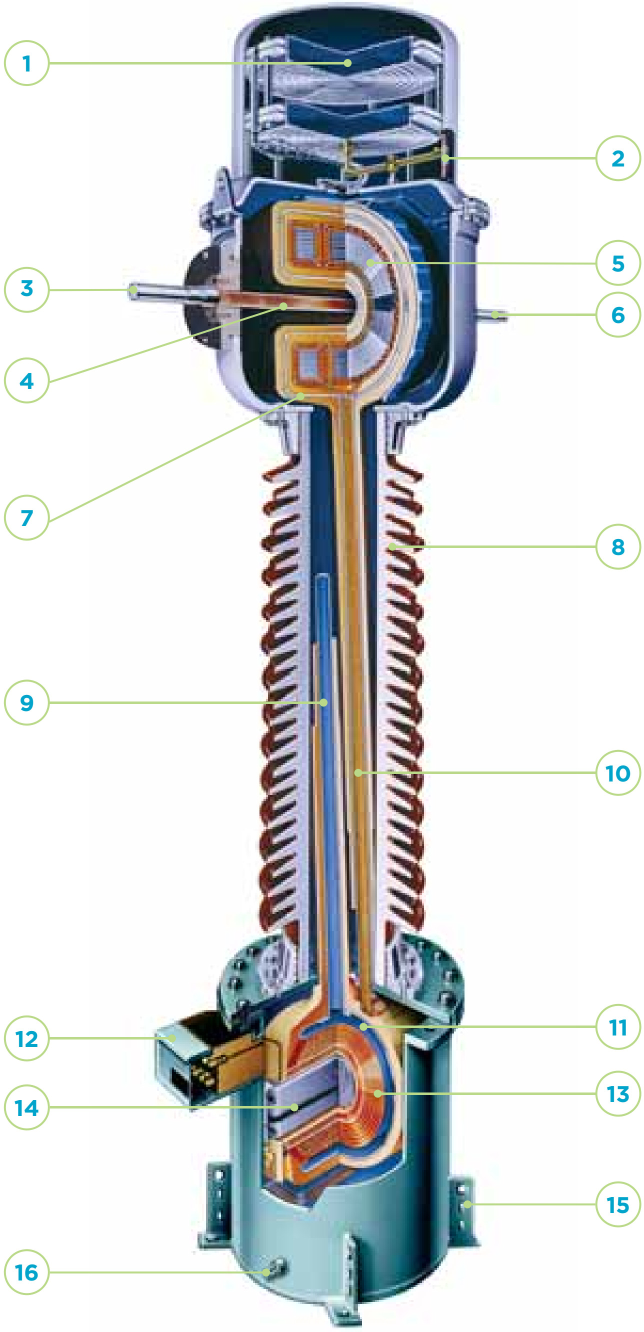
1. Primary terminal
2. Oil volume compensating system
3. Insulator (porcelain or silicone rubber)
4. Capacitors
5. Intermediate voltage tap
6. High frequency terminal
7. Inductive voltage transformer
8. Oil level indicator
9. Carrier accessories
10. Oil sampling valve
11. Grounding terminal
12. Secondary terminal box

› Capacitive voltage transformer.

COMBINED INSTRUMENT TRANSFORMERS

These devices comprise a current transformer and an inductive voltage transformer in the same unit, mainly to save components and space.

The C.T. is placed on the top part of the transformer and the V.T. at the bottom part. Due to the proximity between the C.T. and V.T. their magnetic fields influence each other when taking simultaneous measurements, so the design must be done more carefully to get the same accuracy. It must be also taken into account that if one of the transformers malfunctions and has to be removed from service, the other one is also removed.



1. Oil volume compensating system
2. Oil level indicator
3. Primary terminal (P1)
4. CT primary winding
5. CT secondary winding
6. Primary terminal (P2)
7. CT cores
8. Insulator (Porcelain or silicone rubber)
9. VT capacitive bushing
10. CT capacitive bushing
11. VT primary winding
12. Secondary terminal box
13. VT secondary winding
14. VT core
15. Grounding terminal
16. Oil sampling valve

› Model UTG.

OPTICAL INSTRUMENT TRANSFORMERS

This type of instrument transformers is referred to as “non-conventional transformers”, because they use new technologies to measure current and voltage. Unlike conventional instrument transformers, they are generally based on low-power optical effects to measure current and voltage. They have fiber optic sensors that receive and transmit the signal and built-in electronics to convert the obtained measurements into digital data (usually) or low power analogue signals (±5 V).

Due to the development in microprocessor technologies, almost all measuring and protection equipment is digital, so the measurement from the network (current and voltage) can be transmitted via a communications protocol (i.e. IEC 61850).

The main advantage of these transformers is the insulation between H.V. and earth as all they need is an optic fiber inside an insulator (usually synthetic) to transmit the signal. Electronics in the substation control room process all the data to be transmitted to the measurement and protection equipment.

Optical transformers are much smaller than conventional instrument transformers, and substations using them would only need optic fiber (instead of copper wire). Their main drawbacks are the low experience in operation in the field, and the fact that all the measurement and protection equipment installed at present is designed to be connected to the conventional instrument transformers.

› smART DO Optical transformers. Powerlink (Australia).

5.2. CLASSIFICATION ACCORDING TO SITE CONDITIONS

OUTDOOR INSTRUMENT TRANSFORMERS

These devices are exposed to the environmental conditions (rain, hail and snow). Atmospheric pollution can stain, cover and even attack the surface of the materials. Extreme temperature variations can cause condensation, dew, frost and ice on them. Materials are subject to expansion and contraction. They are also affected by wind, earth movements due to earthquakes or changes in underground water flows. They are also totally exposed to the ultraviolet radiation of the sun.

The material that has traditionally proved highest ability of withstanding these attacks is the porcelain, so it has been used since the beginning of the electrical facilities. The porcelain is a moldable material with an enameled surface practically impervious to chemical aggression, mechanical erosion and the action of light. It is a good insulator and its mechanical resistance complies with the hardest specifications in different operation conditions.

In the last years other materials have been developed as a substitute of the porcelain, due to its drawbacks: price and fragility. Firstly we have the composite insulators, a hollow tube of glass fiber with external silicone cover. These composite insulators are lighter and have more resistance to impacts and explosions. Secondly, in medium voltage, cycloaliphatic resin insulators have been developed as a cost-effective option for these voltage levels.

- Resin insulator. UR voltage transformer.
- Porcelain insulator. CH current transformer.
- Silicone rubber insulator. UG voltage transformer.

The curled shape used is intended to prevent the appearance of conductive films of water, or other substances that may lead to the connection of live parts with those that are grounded.

These insulators must be air tight, so they can be hermetically sealed. It is therefore used as a container for the oil that impregnates the paper insulating the windings. As the oil quickly loses its excellent dielectric properties when polluted by external chemical agents (i.e. water, the most usual and therefore the most dangerous), special care is taken to prevent it from coming in contact with the atmosphere. The air tightness is achieved through an elastic seal, comprising rubbers or metal membranes that adapt to the oil volume changes. Sometimes an inert and compressible gas such as nitrogen is used as the elastic seal.

The insulator for gas insulated instrument transformers is a sealed pressure container, so it is essential to avoid any gas leakage that would definitely lead to a loss of inner pressure and a subsequent loss of the insulation properties.

If very low temperatures (i.e. -50°C) may be reached, the instrument transformer's complete design has to be checked: oil (or gas), rubber used in the gaskets and even the material of the screws and fixing par ts.

If the instrument transformers have to be set up at altitudes between 1,000 and 5,000 m.a.s.l, a careful study of the distribution of the electrical field on the surface of each device must be done. Longer creepage distances must be used (protected creepage distance, flashover distance) due to the lower density and less dielectric power of the air.

INSTRUMENT TRANSFORMERS FOR GAS INSULATED SWITCHGEAR (G.I.S.)

The number of these substations is increasing, mainly for urban locations. All the electrical devices included in these substations are enclosed in a sealed, earthen metal shell containing SF_6 gas under pressure. This gas is an excellent insulator, and provides larger capability to the installation. The construction techniques used in this case differ widely from the common ones, so the instrument transformers are quite different from the conventional ones.

The current transformers are ring-type transformers with low voltage insulation (or up to few tens of kV). They are placed around the tubes that connect the different components. The external diameter of these transformers is quite big and consequently even if their construction is very simple, the ferromagnetic material needed is expensive.

The voltage transformers are usually SF_6 insulated, either as a part of the installation, or separated from the SF_6 part by isolating cones (usually made of resin) and connected to the rest of the installation. Design issues can result from the small space available to homogenize the electrical field and the proximity of the earth foil.

› Voltage transformer for G.I.S.

› Voltage transformers for G.I.S.

INDOOR INSTRUMENT TRANSFORMERS

Indoor instrument transformers are located in places protected from the weather conditions; being the atmospheric effect minimized. They are not exposed to rain, ultraviolet rays or extreme temperatures and the pollution levels are lower than for outdoor transformers.

Due to these circumstances the external surface of the transformers is smooth and featureless, and the main insulator is epoxy resin and other polymers.

The transformers are usually mounted inside buildings or metal-enclosed cubicles (which generally include apparatus and instrument transformers up to 75 kV). Due to the high cost of these constructions, the manufacturers try to reduce the size of the switchgears, and consequently the transformers are placed in different positions.

Therefore, it is possible to find the same type of transformer with slight modifications in the primary and secondary terminals in different installations.

› Instrument transformers in medium voltage switchgears.

5.3. CLASSIFICATION ACCORDING TO INSULATION LEVEL

LOW VOLTAGE INSTRUMENT TRANSFORMERS

Values under 1,000 V are considered low voltages. Accordingly, L.V. instrument transformers require a limited insulation, usually dry, and formed by sheets of paper or polymers. These I.T.s are used in control and measurement panels, they are small sized and encapsulated in plastic or resin.

The current transformers used in the porcelain bushings of power transformers are considered as a separated group. These are ring-type transformers whose dimensions depend on the power transformer's size and voltage level. The outer isolation of these transformers is the porcelain bushing of the power transformer itself, and therefore, they are manufactured with low voltage isolation, saving space and isolation.

As mentioned before in previous chapter of "Instrument transformers for Gas Isolated Switchgears", current transformers are used in GIS switchgears with SF_6 insulation. Internal diameter is usually quite big because they are located around the busbars. Even through this makes these transformers more expensive, they are still of interest due to their simple manufacturing and minimum insulation needs.

MEDIUM VOLTAGE INSTRUMENT TRANSFORMERS

Voltages from 1 to 72.5 kV are considered medium voltages. This is an arbitrary classification, but it mainly matches the voltages used in energy distribution. The classification is modified according to the market trend, which shows an increase in the voltage level used for energy distribution.

In general we can consider the following range of voltages: 7.2 - 12 – 17.5 – 24 – 36 – 52 and 72.5 kV.

Instrument transformers used for this voltage range are mainly indoor transformers. The main target is to save space. The equipment is placed in metal enclosed cubicles, searching for the maximum compactness, and as a result, the primary terminals are modified in order to meet the customer requirements.

In outdoor M.V. instrument transformers, cycloaliphatic resin has been introduced as an alternative to the porcelain insulator. The design of these transformers looks for the maximum safety, sturdiness and economy.

Wall bushing type C.T.s are used for indoor-indoor, indoor-outdoor and outdoor-outdoor installation.

HIGH VOLTAGE INSTRUMENT TRANSFORMERS

The designation of high voltage (H.V.) is mainly for voltages over 72.5 kV, used for energy transmission. The most common values are: 100 - 123 - 145 - 170 - 245 - 300 - 362 - 420 - 550 - 800 kV.

The highest voltages are known as Very-High Voltage, Extra-High Voltage or Ultra-High Voltage. Some years ago 420 kV was considered as E.H.V., but nowadays this classification is given to 525 or, 765 kV, classification that we should be taken just as a guideline.

All voltage transformers used for H.V. are single phase, and combined or capacitive voltage transformers are desirable in some occasions. Furthermore, almost all H.V. instrument transformers are post-type transformers, with porcelain or silicone insulator.

The only H.V. transformers for indoor use are those specially manufactured for Laboratories, they are very similar to the others, but substituting the external insulator for a Bakelite tube.

As the voltages involved in the manufacturing of H.V. equipment are very high, usually cascade type voltage transformers are used. In this design, the voltage is distributed between two or four windings.

Current transformers do not have this disadvantage, because the voltage is established between the primary and secondary windings and not between the ends of the same winding. The secondaries are assembled in a metallic box, isolated from the primary by oil impregnated paper. The secondary low voltage outputs are guided through a metallic tube to the secondary terminal box. This tube is insulated by an oil + paper capacitor wall with metal foils.

Instrument transformers for high voltage. Models DDB, KA, CA and UTF.

6. INDUSTRY REQUIREMENTS FOR INSTRUMENT TRANSFORMERS

I.T.s are manufactured on an industrial scale to meet industrial needs. Their construction and performance characteristics are therefore determined not by theory, but by the industry requirements and needs.

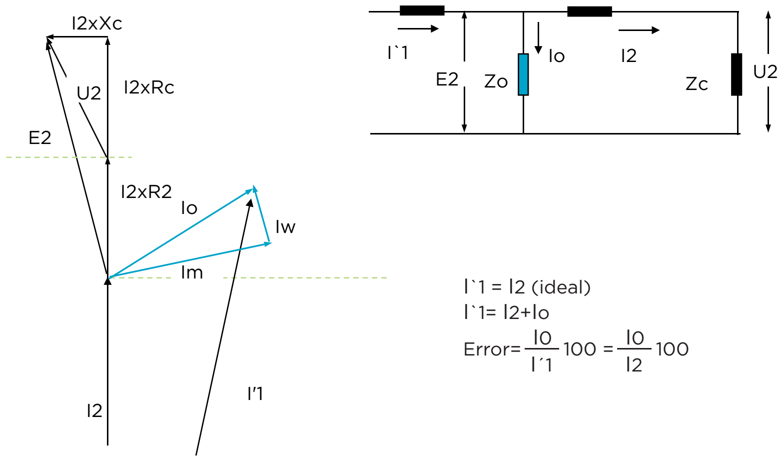
The compromise between industrial requirements and possibilities leads to standards and specifications, drawn up by common agreement between users, manufacturers and corporate bodies which act as arbitrators. As coordination between markets increases, the tendency for standards to converge becomes stronger.

6.1. ELECTRICAL REQUIREMENTS

ACCURACY

Accuracy is the main requirement for instrument transformers. As mentioned before, there are losses due to electromagnetic conversion of energy: the losses in the iron. Furthermore, the current flowing through the conductors causes additional losses, known as the Joule effect. Due to these losses, there is a difference between the incoming and the outgoing energy, therefore an error. Since voltage and current are vectorial values, the error is also vectorial; so there is an error in modulus and an error in magnitude. These are referred to as ratio and phase errors, respectively.

Not all measurements in electrical networks are of the same type or have the same significance; therefore, not all need the same accuracy. The highest accuracy is required for laboratory measurements (research and control) and metering (statistical and billing). Besides, there is a need for control the activity of the network and finally measurements intended merely to give a more qualitative than quantitative idea of the status.



$I'_1 = I_2$ (ideal)

$I'_1 = I_2 + I_o$

$$\text{Error} = \frac{I_O}{I'_1} 100 = \frac{I_O}{I_2} 100$$

6. INDUSTRY REQUIREMENTS FOR INSTRUMENT TRANSFORMERS

With state-of-the-art materials and manufacturing methods, the ratio errors usually considered for the three types of measurement range between 0.1 – 0.2 % for the first type, 0.5% for the second, and 1 – 3 % for the third. The phase errors are between 5 minutes and 1 degree.

The growth of transmission grids, together with the rising power demands of more developed countries, increased the needs to protect these networks against failures. Many of the measurements taken were used to determine whether relays and other protective devices should be activated. This field has become more and more specialized, with specific requirements for I.T.s. These requirements have nothing to do with greater accuracy (it is enough if errors are within the ranges given above for types 2 and 3) but rather with ensuring quick and reliable reporting of any abnormal state.

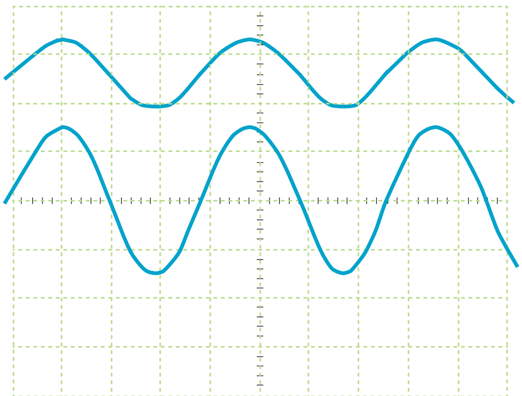
Failures in electrical networks usually entail current or voltage overloads, which are sometimes large enough to saturate the iron core of an I.T. A major concern in protection I.T.s is, therefore, the prevention of saturation; when this happens, the secondary output of the I.T. is no longer similar to the input in form and size, and the protective devices connected to the secondary cannot see what is really going on in the primary (in the grid).

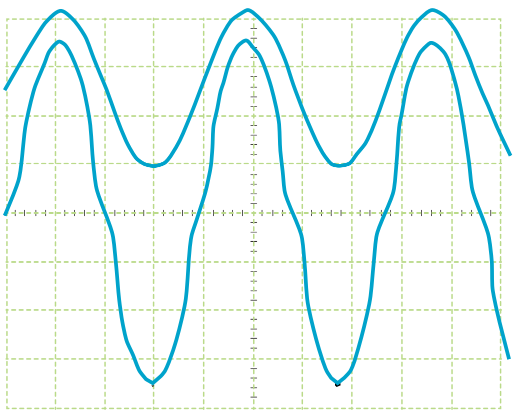
Protective devices must compare the detected conditions with normal foreseeable working conditions so that they can determine whether there has been a failure. In order to do so, they need reliable information of primary conditions even if these are much higher than the normal working conditions for which the system is designed.

Currently, the electricity distribution system is designed to maintain voltage as steady as possible, while the current changes depending on the power generated or consumed. This means that voltage variations should not be too big (no more than double the rated level), but current variations may be much larger (up to one thousand times the rated level in some cases). V.T.s and C.T.s behave, therefore, quite differently as regards protection.

In C.T.s the accuracy limit factor must be defined, indicating how many times greater the primary current to be measured can be compared to rated primary current (i.e. 10, 15, 20, etc.). The error limits must be kept below this limit; so the core must not reach saturation point.

When V.T.s are to be connected to networks in which failure resulting in over voltages may occur, they are required to support 1.5 or 1.9 times their rated voltage for up to 8 hours with no loss of accuracy. This is because it may be necessary for operational reasons to allow the over voltage situation to continue for relatively long periods (whereas in C.T.s all possible efforts are made to minimize the duration of overcurrent failures).





› Comparison between responses from a C.T. without and with saturated core.

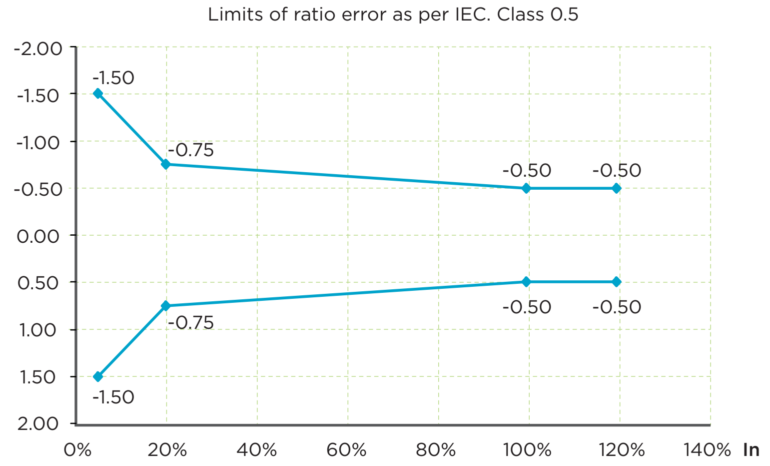
6. INDUSTRY REQUIREMENTS FOR INSTRUMENT TRANSFORMERS

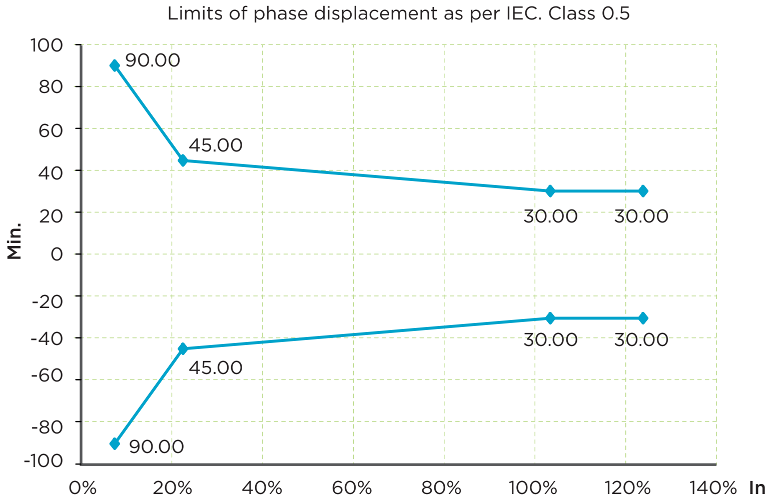
Core saturation is not wanted in protective devices, but it may be required in I.T.s for metering.

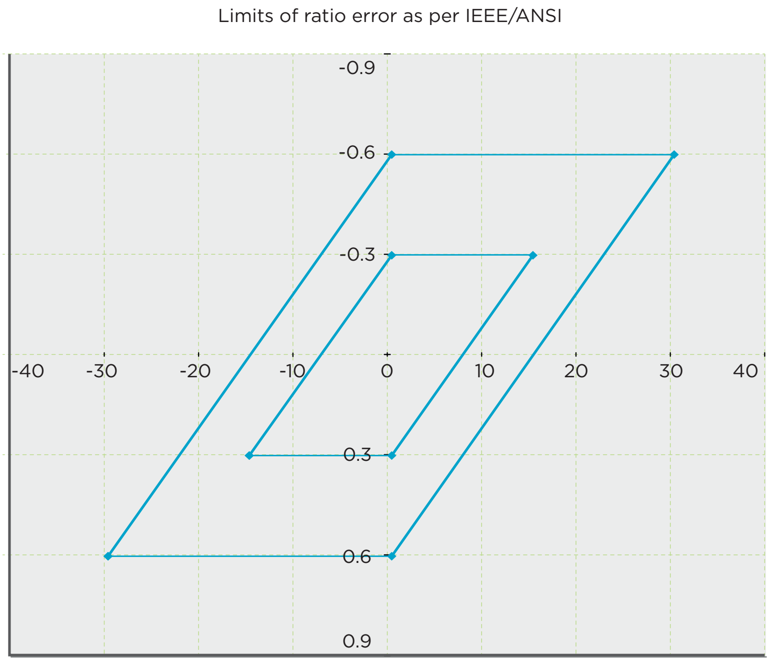
As already mentioned, measuring devices are small and fairly fragile, they are usually only able to handle twice their rated current without damage, but they will be at risk with currents much greater than those for which they are designed. Therefore these C.T.s are designed to saturate when the current reaches certain value (a multiple of the rated level, usually 5 or 10).

Even if the primary current keeps on increasing, once the core is saturated, the secondary current hardly rises, so all and the devices connected are protected. The number of times that the primary current can surpass the rated level before the secondary current ceases to increase (before core saturation) is known as the instrument safety factor.

All I.T.s are checked before leaving the factory to ensure that they meet accuracy requirements, as this is their main requirement. This is why the accuracy test is considered a routine test.







OTHER ELECTRICAL STRESSES

Apart from performing their main function properly, instrument transformers must be suitable for their final location. Several additional tests can be performed, depending on the stresses they may have to suffer. These tests are not run on all the units, but only on those which may have to withstand the situation simulated in each case (i.e. a device which is to be used as a laboratory won't be shock wave tested because it is not expected to be struck by lightning).

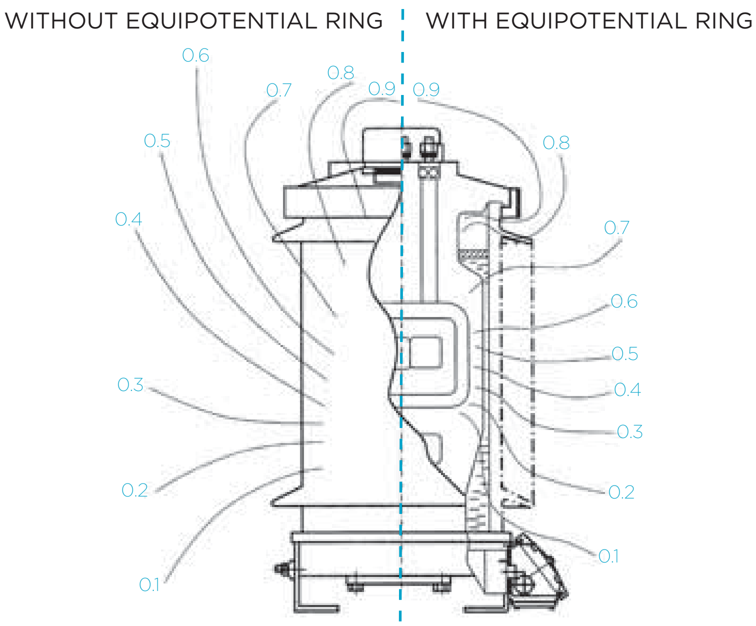
C.T.s may well have to withstand short-circuit currents more than once in their lifetime. The thermal and dynamic consequences of this are the subject of several tests, as will be seen below.

Actual electric networks are designed to operate at the rated voltage, but occasionally even twice this value may be reached and maintained for different periods. The voltage reached and the time to be considered varies according to use and circumstances, so I.T.s are designed with more insulation than required for their rated voltage.

The different standards in force lay down generally accepted voltage levels for testing the dielectric withstand of the transformers. These tests are run on each individual I.T., usually for one minute. The determination of the dielectric strength between the different parts of an I.T. is a routine test (between secondary and primary, between each of them and the core, and finally between each of them against earth or the metal parts of the device. The process is repeated if there is more than one secondary).

Different materials and manufacturing processes lead to different rates of aging and loss of characteristics in I.T.s (i.e. devices which are properly insulated may remain that way for a long time or may just as well lose their dielectric proper ties quickly). Aging has been proved to depend mainly on the degree of homogeneity of the material, how it is manufactured and the electromechanical conditions to which the unit is exposed. Therefore, materials must be carefully selected on the basis quality, uniformity and purity. This applies to resins, paper, oil, tapes, conductors, magnetic plate, etc.

Manufacturing must be done very carefully to ensure good centering, uniform tightness, consistent treatment temperatures, elimination of moisture and a complete and properly distributed impregnation. Careful handling and the use of vacuum for drying and impregnation achieve this.



› Electrical field in a C.T.

arteche

6. INDUSTRY REQUIREMENTS FOR INSTRUMENT TRANSFORMERS

These requirements are taken into account from the design stage, and surfaces are designed with carefully studied shapes to ensure an even distribution of electrical and magnetic fields at suitable levels. It is not possible to find perfect materials, so, for example various layers of paper are applied instead of a single layer of the same thickness to avoid any possibility of granules or imperfections reaching from one side to the other.

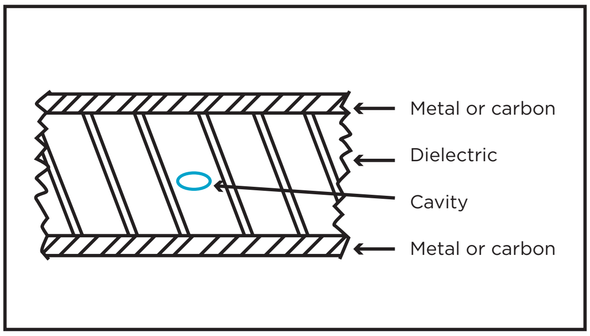
If this uniformity is not achieved, when voltage is applied the magnetic field will be unevenly distributed and some areas will be under more stress than others. In uneven areas (granular inclusions in paper, small gas bubbles in resin, occluded water vapor, etc.), can cause small discharges which break up and damage the dielectric and destroy its properties. Standards and specifications propose various ways of detecting these harmful discharges, and limit the magnitude they can reach without causing premature aging in the I.T.s. The test which gives an idea of insulation quality is referred to as "partial discharge test".

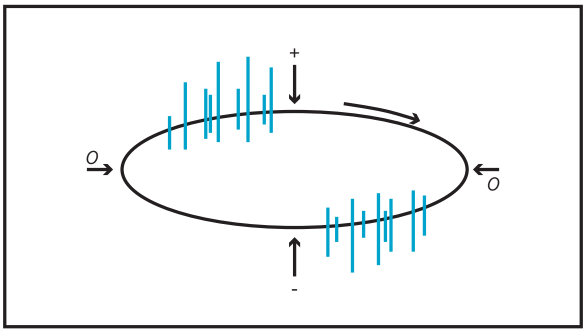
Overhead electricity transport and distribution lines are struck by lightning fairly frequently, which entail very high voltages (many millions of volts), but little energy. When they strike a line, they extend along it, sometimes for considerable distances. If a lightning-type voltage wave goes through an I.T., the insulation suffers an enormous stress for a very short period. This is why I.T.s are required to withstand a certain number of lightning strikes, provided the voltage involved is not extremely high.

The type tests laid out by the different standards require the I.T.s to undergo a set number of shock waves with predefined polarity, form and magnitude. By "type test" we mean a test not performed on all devices but only on one of each type, in the belief that if they are designed and manufactured similarly, they should all have similar characteristics. Some standards establish tests with a chopped impulse wave in order to distinguish between the behavior of the external and the internal insulation of a device.

In some cases this test must be carried out in the rain, to simulate the worst circumstances which may prevail in actual conditions.

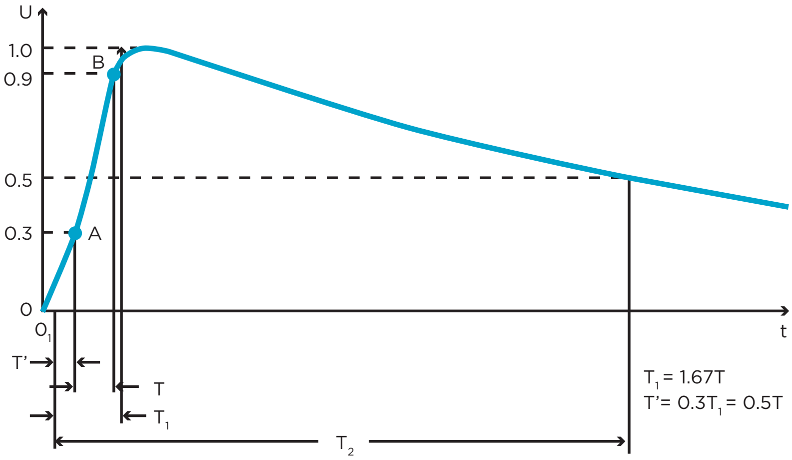
The opening and closing of switches may also cause transient over voltages in H.V. networks similar to those caused by lightning, but with more energy, which must be dissipated. Sometimes a switching impulse wave test is also requested as type test.





› Defect in a dielectric (cavity).

› Formalised discharge pattern.



› Lightning impulse.

6. INDUSTRY REQUIREMENTS FOR INSTRUMENT TRANSFORMERS

Some devices are to be installed in places particularly exposed to very high voltage lightning strikes, as the weather in some geographical areas has very high isokeraunic levels. There are also lines and substations with control operation that may cause very high voltage waves. In all these cases conventional lightning impulse wave insulation is not enough, so encapsulated spark gaps or auto-valve arresters are used.

Lightning impulse waves involve two main issues. The wave may simply move along the line, causing enormous potential differences between adjacent points, which would destroy their insulation. This might occur mainly in C.T.s, where insulation around the primary conductor is relatively weak. To prevent this, a spark gap is fitted in parallel with the winding and set for a voltage lower than the harmful one, so that an external spark would consume most of the energy from the lightning wave. The other possibility is that the lightning impulse wave may discharge to earth from the line through the I.T., destroying the insulation between H.V. and L.V. In this case, rod-type outside discharge units are fitted. In the case of C.V.T.s used as Coupling Capacitors, auto-valve arresters are needed fitted in parallel with the drainage coil.

Even other electric phenomena may have to be considered, which can influence the selection of the I.T. and the tests it may have to go through. In some networks a ferroresonance effect is produced which causes major overcurrents with thermal and dynamic effects similar to those of a short circuit.

If an I.T. is to be set up far above sea level, the rarefied atmosphere is to be taken into account, as the dielectric power of the air will be less than normal and this may cause insulation problems. Similar complications may arise in highly humid coastal areas, highly polluted areas, or very cold or hot areas. All these abnormal conditions are relevant for the electric design of the devices, and specific type tests are usually per formed to prove suitability.

› Dielectric routine tests in Ultra-High Voltage laboratory.

6.2. OTHER REQUIREMENTS

MECHANICALS

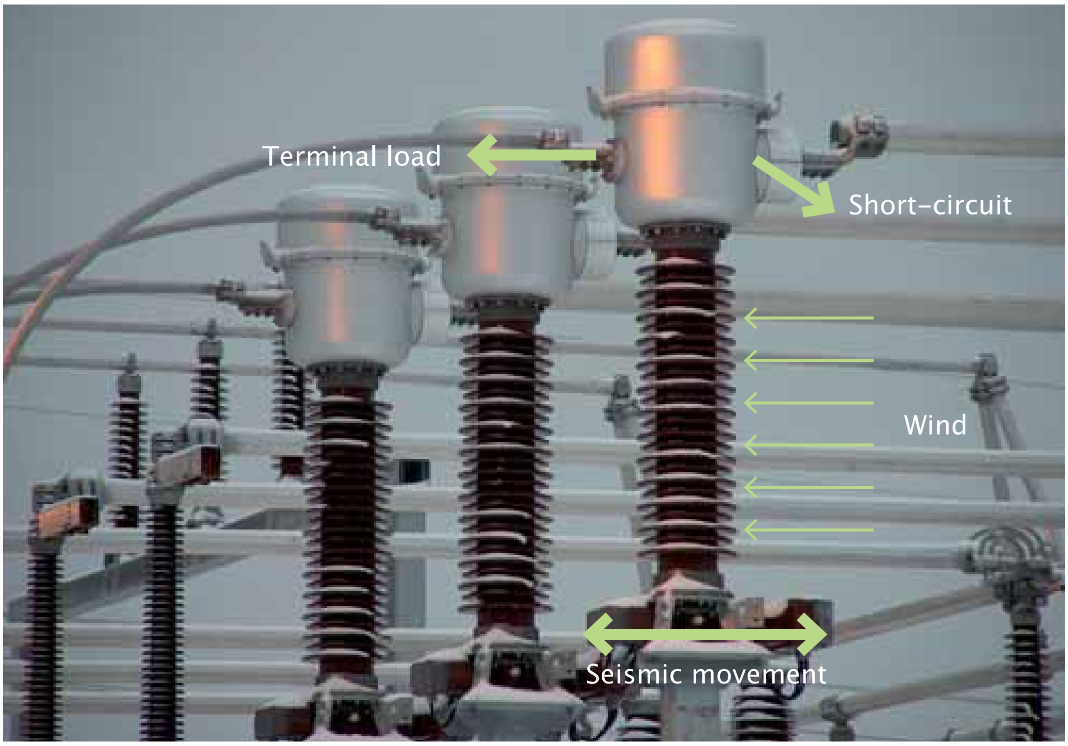
If there is a short circuit in a line where a CT is located, a very high current will flow through the transformer's primary. When current passes through the conductor, it generates a magnetic field, as explained in point 2 above. The short circuit current is much higher than the rated level, so the magnetic field is also much more intense than that for which the device is designed. A conductor inside a magnetic field tends to take up a position in space in accordance with field lines. If the C.T. primary is wound, the magnetic fields created by the current as it passes though the opposite sides of each turn, clash and tend to deform the winding. As the primary attachment system is designed for the rated operating conditions, a short circuit current strong enough may deform it to the point of breaking its attachment and destroying the whole device. Therefore customers must indicate the highest short-circuit current they expect the C.T. to suffer, so that the unit may be designed and manufactured accordingly.
Dynamic short-circuit tests at the most unfavorable ratio are usually carried out on each design type to determine the maximum number of dynamic ampere-turns that each type of C.T. can withstand without damage. This is, of course, a type test.

If the C.T. is fixed straight bar type, it is guaranteed to withstand any short-circuit occurring in normally designed networks, as the conductor itself creates the only major magnetic field present, and this has no harmful effects on it.

In outdoor facilities, conductors are suspended from insulation chains, and sometimes from I.T.s, in which case they pull hard on the primary terminals. Expecting these situations, type tests are also performed to determine the maximum stresses allowed on the terminals in the different directions.

In locations subject to high winds, the force of the wind must be taken into account when selecting an I.T.

In seismic areas the I.T. must be able to withstand the vibratory stresses caused by earthquakes. There are type tests to determine their performance.



› Mechanical stresses on a transformer.

6. INDUSTRY REQUIREMENTS FOR INSTRUMENT TRANSFORMERS

THERMALS

All I.T.s suffer internal losses which are converted into heat. There are losses due to the Joule effect in conductor windings and core losses due to Foucault currents and hysteresis. There are losses in the dielectric due to leakage currents, which will increase dramatically and become quite significant when the temperature rises. The heat must be dissipated to the atmosphere to prevent heating damages due or premature aging.

I.T.s are designed to do this properly in normal and also under certain anomalous conditions specified in standards. External environmental conditions can vary dramatically from season to season and one location to another. The maximum and minimum ambient temperature and the internal part maximum temperature rise are indicated in standards and type tests are performed under those conditions.

If there are short-circuits or other events which cause heavy overcurrent, such as ferroresonance, the losses due to the Joule effect become very large indeed. If the protective devices fail to act on time the I.T. will burn out. Transformers must be able to withstand such overheating without damage for a short time (usually 1 or 3 seconds) to give the protective devices time to act. This thermal effect of short-circuits in short duration currents is taken into account in design, and devices are made to suit the user's needs according to the short- circuit power in their networks. There are also type tests for these situations.

Weather effect is very important here, and there are many circumstances to be considered. These include very hot or cold locations, heavy rainfall or high humidity, locations w h e re the temperature can vary from very high to very low in a matter of hours, location where the humidity varies from almost zero to saturation and many other meteorological and environmental considerations. All these must be taken into account in each case, in accordance with their consequences, for the design and thermal performances of I.T.s.

CHEMICALS AND OTHERS

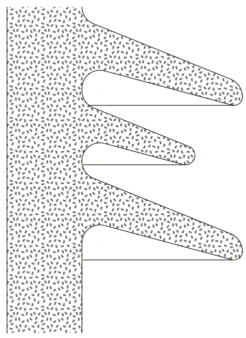
The materials used to manufacture I.T.s must be resistant to chemicals in the environment where the devices are located. The nature of aggressive substances must be studied. The corrosion of metal parts in humid, coastal areas or heavily polluted areas with aggressive atmospheres can make it necessary to use stainless steel, electroplated coatings (metalized, galvanizing, chrome-plating, etc.) primers and paints.

Resins used for outdoor applications must be studied carefully to determine whether the ultraviolet radiation from sunlight can affect them. Ozone is formed around H.V. Parts, so sufficient ventilation must be ensured to prevent rubber, lacquer, paint and other elements from being damaged by ozone action.

Rain, hail, snow and ice form conductive paths over the insulator surface, so these components are made with vanes of different shapes and sizes, with ridges and depressions to hinder the formation of such paths. Coal dust and sulphur compounds in mining and industrial areas can also combine with the mentioned atmospheric conditions to form mud and chemically aggressive incrustations, too.

Sandstorms abrade surfaces and destroy protective coatings, so that special or extra-thick coatings must be used.

Whether they occur separately or together, these requirements mean that I.T.s must be designed with care to suit their jobs and locations. When circumstances are very different from those indicated in the standards, the customer and manufacturer must get together and draw up specifications including special tests for that specific order. Alternatively, this may be left in the hands of the manufacturer as a mark of the customer's trust in its record and the reputation it has built up for itself.



› Porcelain sheds.

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