Chapter 02: Protection System Contents

1. Introduction

Protection is the branch of electric power engineering concerned with the principles of design and operation of equipment (called ‘relays’ or ‘protective relays’) that detects abnormal power system conditions, and initiates corrective action as quickly as possible in order to return the power system to its normal state. The quickness of response is an essential element of protective relaying systems – response times of the order of a few milliseconds are often required.

The human intervention in the protection system operation is not possible. The response must be automatic, quick and should cause a minimum amount of disruption to the power system. The entire subject is governed by these general requirements: correct diagnosis of trouble, quickness of response and minimum disturbance to the power system.

2. Elements of a protection system

The protection system contents is depicted in the fig.2.1

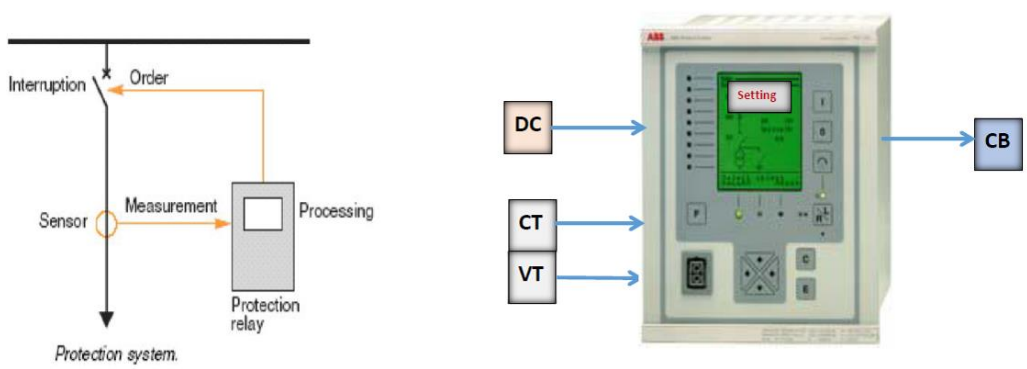


Fig.2.1 the contents of protection system

1. Battery and dc supply

When the AC voltage available in the substation may not be of sufficient magnitude. For example, a close-in three-phase fault can result in zero AC voltage at the substation AC outlets. Tripping power, as well as the power required by the relays, cannot therefore be obtained from the AC system, and is usually provided by the station battery.

Fig.2.2 Battery accumulator

The battery is also rated to maintain adequate DC power for 8-12 hours following a station blackout.

The battery is permanently connected through a charger to the station AC service, and normally, during steady-state conditions, it floats on the charger.

2. Circuit breaker

Circuit breakers are fault-interrupting devices that enable or interrupt the flow of current to power system components.

Circuit breakers of several designs can be found in a power system, and it's name is according to the medium used to interrupt the fault current In addition, better insulating materials, better arc quenching systems and faster operating requirements resulted in a variety of circuit breaker characteristics: interrupting medium of oil, gas, air or vacuum; insulating medium of oil, air, gas or solid dielectric.

Operating mechanisms using impulse coil, solenoid, spring–motor–pneumatic or hydraulic.

2.1 Standards

Relevant National and important international standard in this connection are as follows:

1. IS: 13118/ IEC56 - Specification for high-voltage alternating current circuit breakers
2. IEC: 62271 - High voltage alternating current circuit breakers
3. IEEE: 37010 - IEEE Application Guide for AC high voltage circuit breakers
4. IEEE 37013 - AC high voltage generator circuit breaker rated on symmetrical current basis

Note: IEC 56 was withdrawn in 2001 and replaced by IEC 62271-100

2.2 Type of HV Circuit Breakers

Following types of circuit breakers formerly used in high voltage outdoor substations are no longer in use and are being phased out.

1. **Bulk oil circuit breakers (Dead Tank Design)**:

In these circuit breakers oil content is used for arc extinction and also for insulating live parts from the tank which is dead and generally earthed (grounded).

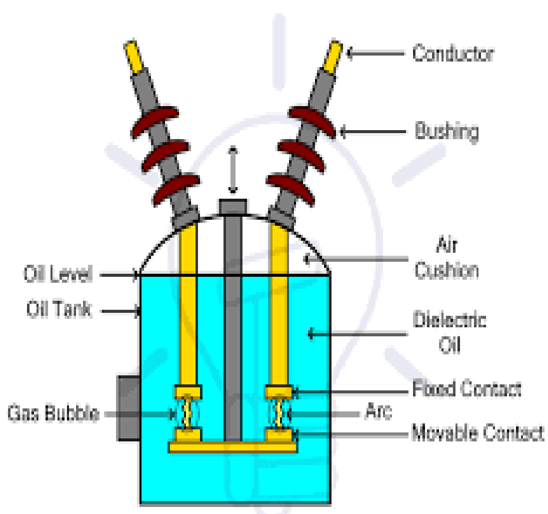


Fig.2.3 Bulk oil circuit breaker

2. **Minimum oil breakers (Live Tank Design):**

In these circuit breakers oil is primarily used for arc extinction and not necessarily for insulating live parts from earth (ground). The tank of these circuit breakers is insulated from earth ground. The circuit breakers are phase separated. These circuit breakers were widely used up to 72 kV level and are being phased out from existing installation.


Fig.2.4 Minimum oil breakers

3. Air blast circuit breaker

Circuit breaking in these circuit breakers occurs in a blast of air under pressure. These circuit breakers were widely used up to 765 kV system. These circuit breakers are also being phased out.

Following types of circuit breakers (for max. voltage class) are in use now-a-days substations.

1) SF-6: Sulphur Hexa Flouride Breakers 36 kV to 765 kV
2) Vacuum circuit breakers up to 36 kV
3) Air circuit breaker up to 12 kV

3. Transducers

The function of current and voltage transformers (collectively known as transducers) is to transform power system currents and voltages to lower magnitudes, and to provide galvanic isolation between the power network and the relays and other instruments connected to the transducer secondary windings.

The ratings of the secondary windings of transducers have been standardized, so that a degree of interchangeability among different manufacturers’ relays and meters can be achieved. In the USA and several other countries, current transformer secondary windings are rated for 5 A, while in Europe a second standard of 1 A secondary is also in use. Voltage transformer secondary windings are rated at 120 V for phase-to-phase voltage connections, or, equivalently, at 69.3 V for phase-to-neutral connections.

1. Current transformers:

It is an instrument that reduce the heavy current to lower values suitable to be fed to protective relays and measurement, also, it isolates secondary circuit from the primary which is a voltage power circuit. The CT permit the use of standard current ratings for secondary equipment.

Fig.2.5 different type of CTs

2.1 Current transformer construction

The primary winding is connected in series with the supply's load, and it will pass the full load current and fault current.

The bar primary of CT is further simplified by using the main conductor itself as the single primary turn-giving us the slip over ring CT, the most widely used type bar primary CTs are common at transmission voltages.

The secondary winding will have larger number of turns dependent on the required turns ratio. Most CTs have a toroid wound secondary winding on a laminated core.

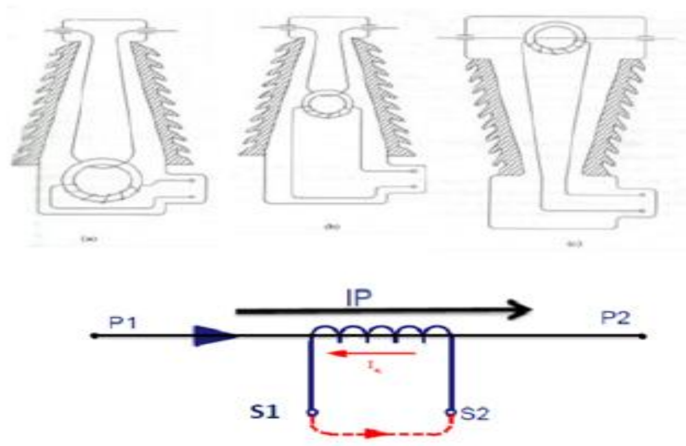


Fig.2.6 Construction of CTs

2.2 CT symbol

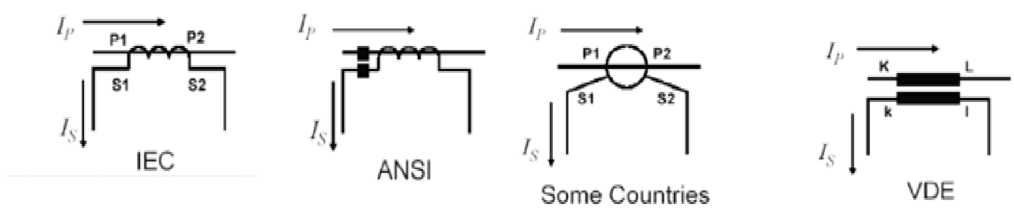


Fig.2.7 CT symbol

2.3 Classification of CT according the uses

1-CT used for protection

2-CT used for measurement

The above classifications depending on core material manufacture (magnetization of CT cores):

- Cold-rolled non oriented silicon steel (used for protection)
- Hot- rolled non oriented silicon steel (used for protection)
- Nickel-iron core (80% Nickel) (used for measurement)

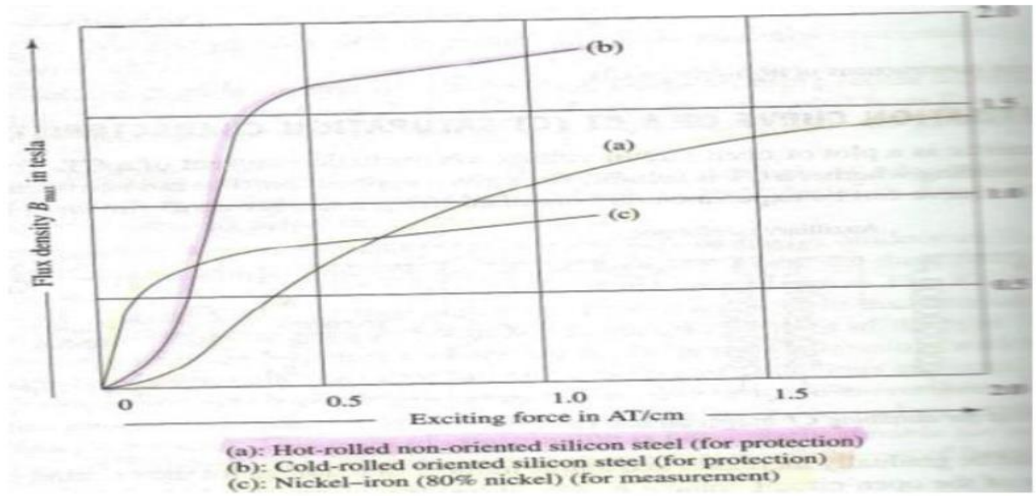


Fig.2.8 CT characteristic in term of magnetic core

2.4 Characterization of CTs

An example of name plate of a protection CT

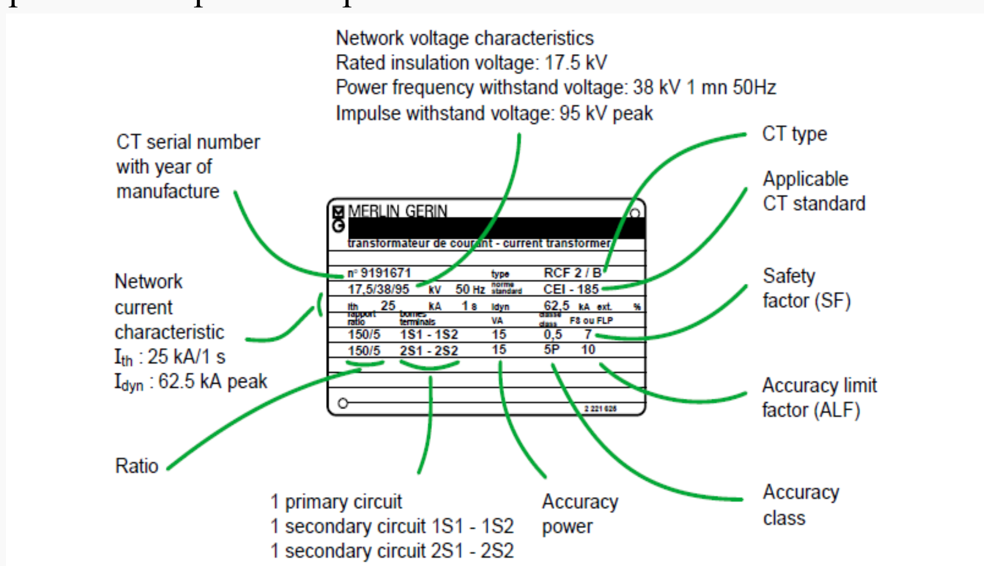
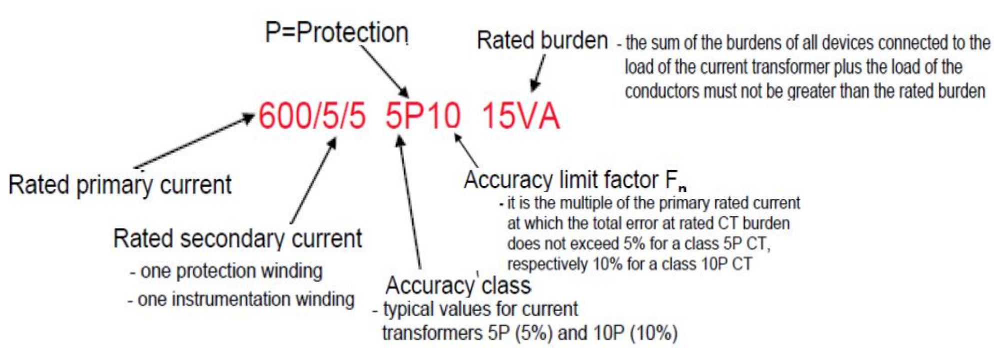
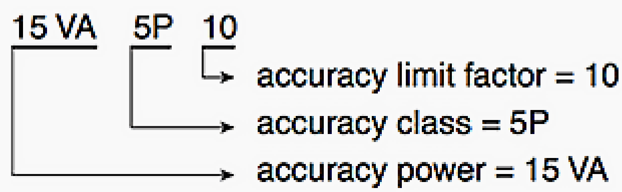


Fig.2.9 Nameplate of a current transformer



- Rated primary current: 600 A,
- Rated secondary current: 5 A.



- Its accuracy load: Pn = 15 VA
  Its accuracy limit factor is ALF = 10
- To simplify, for the protection CT given in example, the ratio error is less than 5% at 10 In , if the real load consumes 15 VA at In.

1. **Rated (nominal) primary current I1**

Defined by standards, it is chosen from the discrete values:

10-12.5- 15-20-25-30- 40- 50- 60-75 A and their decimal multiples.

2. **Rated (nominal) secondary current I2**

Equals 1A or 5 A.

3. **Ratio (I1 / I2)**

The primary and secondary currents are standard.

4. **Accuracy load**

Load value on which the accuracy conditions are based.

5. **Rated (nominal) accuracy power Pn**

Expressed in VA, it is the apparent power supplied to the secondary circuit for the nominal (rated) secondary current and the accuracy load. The standard values are: 1- 2.5- 5-10- 15- 30 VA.

6. Accuracy class

This class defines the error limits guaranteed on the ratio and on the phase shift in specified power and current conditions. For the nominal 5P and 10P classes, the table in bellow defines these limits. (according to standard IEC 60044-1)

Accuracy class	Current error for the nominal current as a %	Phase shift for the nominal current		Composite error for the accuracy limit current as a %
		Minutes	Centiradians	
5P	± 1	± 60	± 1.8	5
10P	± 3	–	–	10

Tab.2.1 Errors on the module and the phase at nominal current according to standard IEC 60044-1

2.5 Knee point voltage of CT

The knee point voltage V_k is defined as the point on this curve from which a 10% increase in voltage causes a 50% increase in the magnetizing current Io.

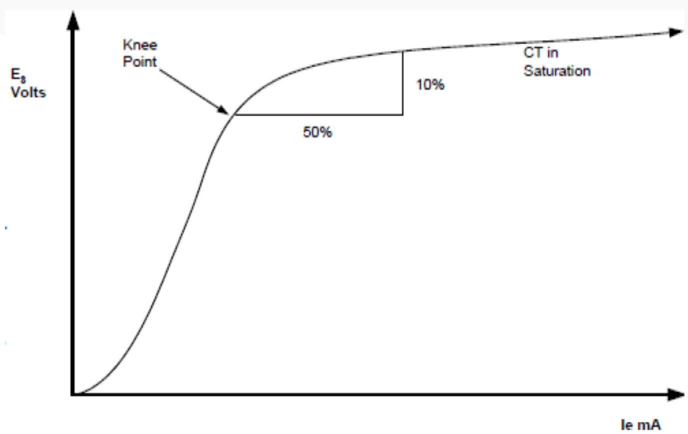


Fig.2.10 Knee point of CT

The secondary knee point voltage is directly related to core saturation nearing the practical limit of working for the CT.

If the primary current increase. The core flux will increase, To much current will drive a CT into saturation.

2.5.1 Calculate the knee point of CT

A CT information is Ratio 300/5, 5P10, 60VA, the calculation of the knee point is $V_k = 10x60/I_S = 10x60/5 = 120V$

2.6 Effect of saturation

The effect of saturation shown in figure bellow

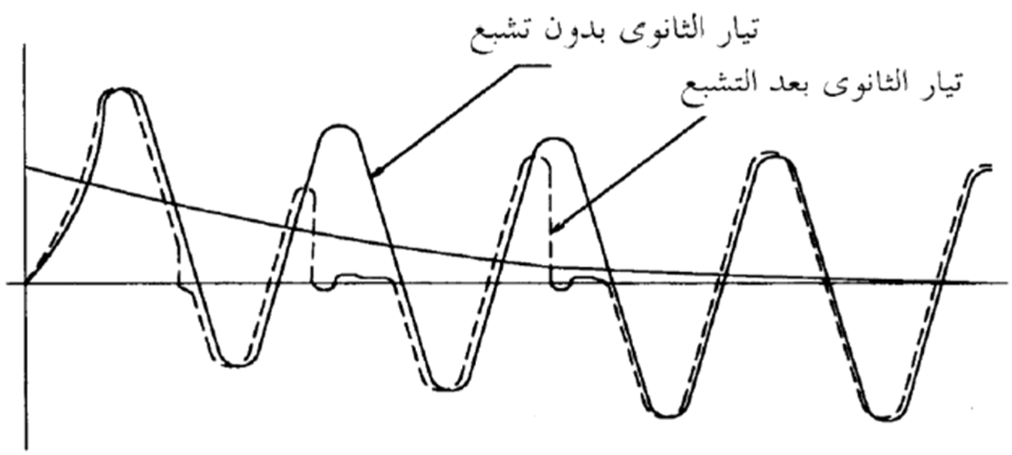


Fig.2.11 Effect of saturation in CT

2.7 Open circuit of CT

1. It is very important for all operation technical must not be open circuit of CT
2. Because the EMF induced in the secondary winding is that required to drive the secondary current through the load impedance and excitation
3. This EMF value is depending on primary current load
4. The primary gets overheated and the core also gets overheated
5. In this case the voltage across the open secondary winding rises to a high value may be reach some kilo volts. This value of voltages is harmful to the CT secondary insulation and insulation of the control and protection cable

2.8 Choosing CTs according to protections and applications

1. The protection relays installed on an electrical network are defined in the protection plan.
2. This plan specifies the position and setting of the selected protections. It also defines the position of the CTs, their ratio and, more rarely, their power,

accuracy and ALF. In point of fact (Fig.2.12), complete specification of CTs also requires knowledge of:

1. the protection input impedance,
2. the wiring impedance,
3. the protection operating thresholds (normally taken into account in the protection co-ordination study).

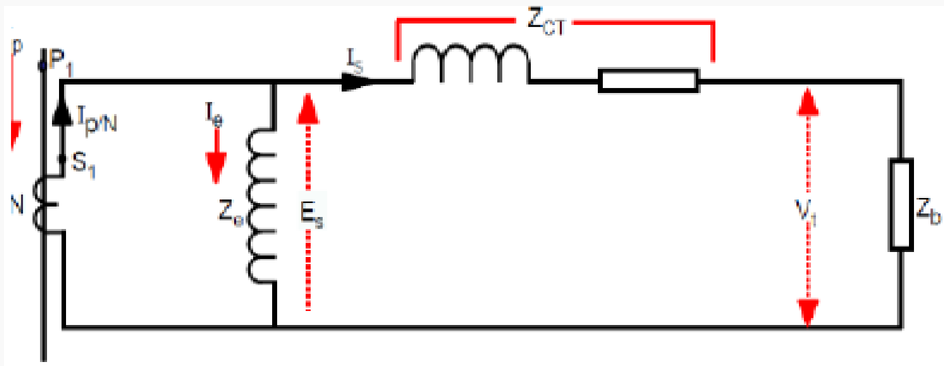


Fig 2.12 CT model

The type of protection also affects the required CT accuracy:

1- an overcurrent protection only takes the current value into account,

2- a differential protection compares two currents,

3- an earth fault protection treats the sum of the three phase currents.

Operating mechanisms using impulse coil, solenoid, spring–motor–pneumatic or hydraulic.

6. Polarity markings on CT windings

Polarity markings of transformer windings are a means of describing the relative directions in which the two windings are wound on the transformer core.

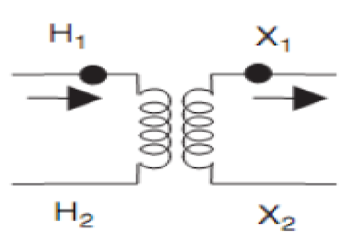


Fig.2. 13 Polarity of CT

Voltage transformers

Voltage Transformers (VTs) are also classified along with Current Transformers (CTs) as Instrument Transformers. These are shunt connected devices intended to reproduce Secondary Voltages in fixed proportion to the Primary system Voltage.

Main purpose of a VT is to produce replica of a system voltage which can be used in Metering & Relaying systems maintain required accuracy over range of Voltage.

Two types of Voltage Transformers are most commonly used in Metering, Protection & control systems are Measuring (Metering):

Voltage Transformers and **Protective (Relaying) Voltage Transformers**.

1. **Voltage Transformer:** an instrument transformer intended to have its primary winding connected in shunt with the voltage to be measured or controlled. This type of VT is used up to 66Kv. For lower voltage, to 3.3 Kv, a dry type VT with varnish impregnated and taped winding are generally used. For higher voltage the core and windings are immersed in oil. For voltage above 6Kv electromagnetic PTs are generally in cascade connection. At higher voltages, electromagnetic type PTs becomes very expensive

2. **Capacitor voltage transformer CVT:** a voltage transformer comprising a capacitor divider unit designed and interconnected that the secondary voltage is substantially proportional to the primary voltage

The size of electromagnetic voltage transformers for the higher voltages is largely proportional to the rated voltage; the cost tends to increase at a disproportionate rate. The capacitor voltage transformer (CVT) is often more economic.

A reactor possesses some resistance, which limits the output that can be obtained. For a secondary output voltage of 110V, the capacitors would have to be very large to provide a useful output while keeping errors within the usual limits. The solution is to use a high secondary voltage and further transform the output to the normal value using a relatively inexpensive electromagnetic transformer. The successive stages of this reasoning are shown in Fig.2.14 Development of capacitor voltage transformer.

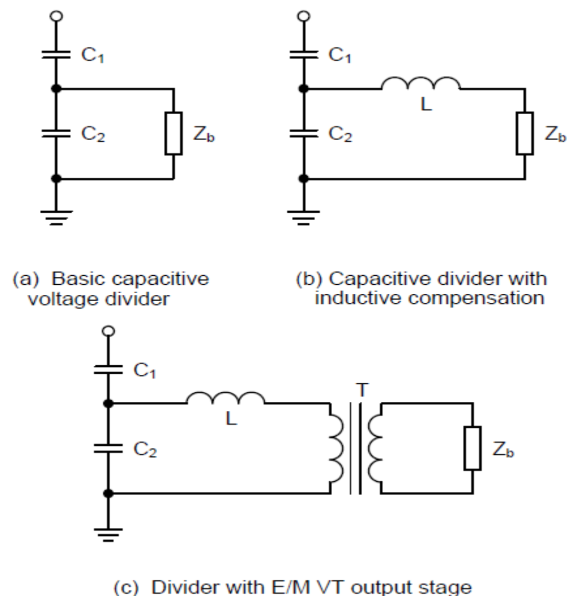


Fig.2.14 Development of capacitor voltage transformer

Standard values for VTs as defined in IEC 60044-2 :

The rated secondary voltage shall be chosen according to the practice at the location where the transformer is to be used.

A. Based on the current practice of a group of European countries:

   a. 100V and 110V

   b. 200V for extended secondary circuits

B. Based on the current practice in the United States and Canada

a. 120V for distribution systems

b. 115 V for transmission systems

c. 230V for extended secondary circuits

VT Parameters

1. Rated primary voltage (Up):

Depending on their design, voltage transformers will be connected either:

1. Between phase and earth (see Figure 1a); or
2. Between phases (see Figure 1b).

$$\frac{3,000}{\sqrt{3}} / \frac{100}{\sqrt{3}} \qquad U_p = \frac{U}{\sqrt{3}} \qquad\qquad 3,000/100 \qquad U_p = U$$

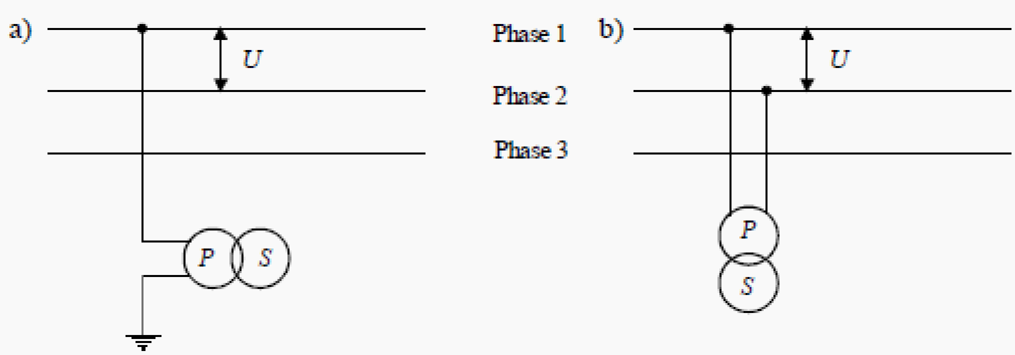


Fig.2.15: Voltage transformer connections

Fig.2.16 voltage transformer connection type

The voltage transformer must be suited to requirements relating to protection and measuring devices. The foreseen application of the voltage transformer is used to determine the rated secondary voltage, the accuracy power, the accuracy class and the thermal power limit.

1. Rated voltage factor: this is the factor by which the rated primary voltage must be multiplied in order to determine the maximum voltage for which the transformer must attain the required levels of heating and accuracy.

$$\frac{100}{\sqrt{3}}$$

2. Accuracy power: this is expressed in VA and it is the apparent power that the voltage transformer can supply to the secondary when it is connected under its rated primary voltage and connected to its accuracy load. It must not introduce an error in excess of the values guaranteed by the accuracy class. The standardized values are: 10-15- 25- 30- 50- 75- 100- 150- 200- 300 -400- 500VA.
3. Accuracy class: this defines the guaranteed transformation ratio and phase error limits in specified power and voltage conditions.

4. Voltage ratio error: this is the error that the transformer introduces in the voltage measurement:

$$\text{voltage error (\%)} = \frac{\left(K_n\, U_s - U_p\right)\times 100}{U_p}$$

Table 2.2 gives the accuracy class generally used in accordance with the corresponding application.

Table 2.2 the accuracy class depends application

Application	Accuracy class
Not used in industry	0.1
Precision metering	0.2
Usual metering	0.5
Statistical metering and/or measurement	1
Measurement not requiring high accuracy	3

The accuracy class is guaranteed if the voltage is between 80 and 120% of the rated primary voltage and for any load between 25 and 100% of the rated accuracy power with an inductive power factor of 0.8.

The standardized IEC accuracy classes are: 0.1-0.2- 0.5- 1- 3.

1. Classes 0.1 and 0.2 are only used for laboratory devices.
2. Classes 0.5 and 1 are used in the majority of cases.

3. Class 3 is used very little.

Relay designs

Relays are devices requiring low-level inputs (voltages, currents or contacts). They derive their inputs from transducers, such as current or voltage transformers, and switch contacts. They are fault-detecting devices only and require an associated interrupting -device a circuit breaker- to clear the fault.

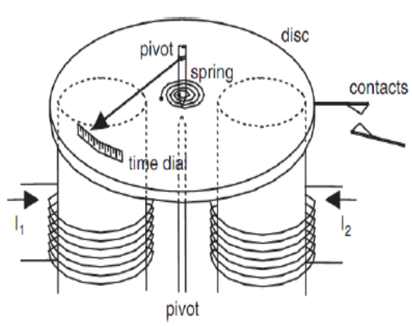
1. **Fuses**

The fuse is a level detector, and is both the sensor and the interrupting device. It is installed in series with the equipment being protected and operates by melting a fusible element in response to the current flow. The melting time is inversely proportional to the magnitude of the current flowing in the fuse.

2. **Electromechanical relays**

The early relay designs utilized actuating forces that were produced by electromagnetic interaction between currents and fluxes, much as in a motor.

In electromechanical relays, the actuating forces were created by a combination of the input signals, stored energy in springs and dashpots.



an induction disc relay.

Fig.2… an induction disc relay

3. **Solid-state relays**

All of the functions and characteristics available with electromechanical relays can be performed by solid-state devices, either as discrete components or as integrated circuits.

Solid-state relay circuits may be divided into two categories: analog circuits that are either fault sensing or measuring circuits, or digital logic circuits for operation on logical variables.

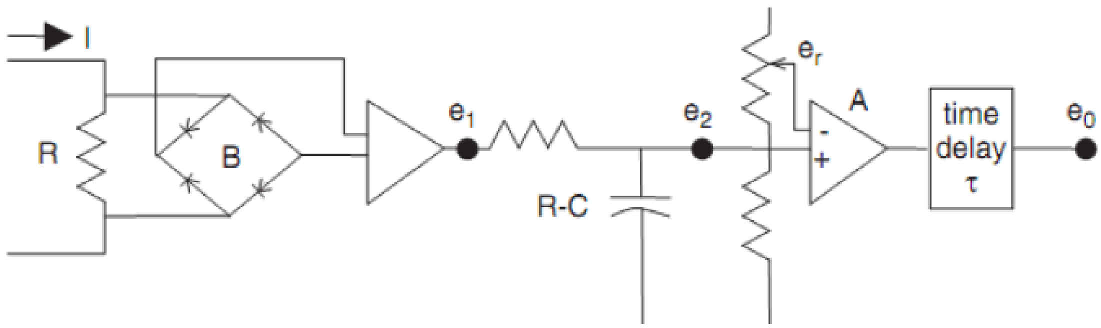


Fig.2… Configuration for solid-state instantaneous overcurrent relay

4. Computer relays

The observation has often been made that a relay is an analog computer. It accepts inputs, processes them electromechanically, or electronically, to develop a torque, or a logic output representing a system quantity, and makes a decision resulting in a contact closure or output signal. With the advent of rugged, high-performance microprocessors, it is obvious that a digital computer can perform the same function. Since the usual relay inputs consist of power system voltages and currents, it is necessary to obtain a digital representation of these parameters. This is done by sampling the analog signals, and using an appropriate computer algorithm to create suitable digital representations of the signals.

This is done by a digital filter algorithm. The functional blocks shown in Figure represent a possible configuration for a digital relay.

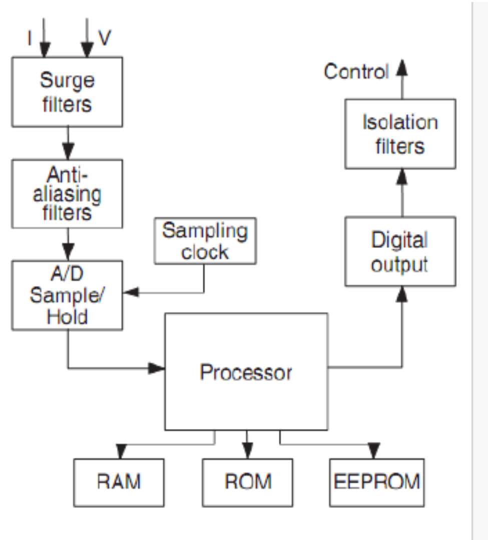


Fig.2… Major subsystem of a computer relay

Different relays

Relay Family

Relay

Electro Magnetic | **Static** | **Mechanical**

Based on Characteristic

1. Definite time Relays
2. Inverse time Relays with definite minimum time (1 DMT)
3. Instantaneous Relays
4. IDMT with inst.
5. Stepped Characteristic
6. Programme Switches
7. Voltage restraint overcurrent relay

Based on actuating parameter

1.Current Relays
2. Voltage Relays
3. Frequency Relays
4. Power Relays etc.

Based on of logic

1. Differential
2. Unbalance
3. Neutral Displacement
4. Directional
5. Restricted Earth Fault
6. Over Fluxing
7. Distance Schemes
8. Bus bar Protection
9. Reverse Power Relays
10.Loss of excitation
11.Negative Phase Sequence Relays etc.

1. Thermal
(a) OT Trip
(b) WT Trip
(C) Bearing Temp Trip etc.
2. Float Type
(a) Buchholz
(b) OSR
(c) PRV
(d) Water level Controls etc.
3. Pressure Switches
4. Mechanical Interlocks
5. Pole discrepancy Relay

Fig.2…Family of relay