INTRODUCTION TO POWER SYSTEM PROTECTION

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1) Introduction

Power system protection systems have three basic components: Instrument transformers, Relays, Circuit breakers

The function of the CT is to reproduce in its secondary winding a current I’ that is proportional to the primary current I. The CT converts primary currents in the kiloamp range to secondary currents in the 0–5 ampere range for convenience of measurement.

The function of the relay is to discriminate between normal operation and fault conditions. The OC relay in Figure 2 has an operating coil, which is connected to the CT secondary winding, and a set of contacts. When |I’| exceeds a specified ‘‘pickup’’ value, the operating coil causes the normally open contacts to close. When the relay contacts close, the trip coil of the circuit breaker is energized, which then causes the circuit breaker to open.

System-protection components have the following design criteria:

- Reliability: Operate dependably when fault conditions occur, even after remaining idle for months or years. Failure to do so may result in costly damages.
- Selectivity: Avoid unnecessary, false trips.
- Speed: Operate rapidly to minimize fault duration and equipment damage. Any intentional time delays should be precise.
- Economy: Provide maximum protection at minimum cost.
- Simplicity: Minimize protection equipment and circuitry.

Since it is impossible to satisfy all these criteria simultaneously, compromises must be made in system protection.

The book consists from the following sections:

1. Chapter 1: Power System Faults:
2. Chapter 2: Instrument Transformers.
3. Chapter 3: Overcurrent and Earth Fault Protection Relays.
4. Chapter 4: Radial System Protection.
5. Chapter 5: Zones of Protection.
6. Chapter 6: Differential Relays.
7. Chapter 7: Distance Relays.
8. Chapter 8: Transformer Protection.
9. Chapter 9: Generator Protection.
10. Chapter 10: Busbar Protection.
11. Chapter 11: Circuit Breakers.
12. Chapter 12: Fuses.
13. Chapter 13: References.

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2) Chapter 1: Power System Faults

1. Power systems principals:

In general, the definition of an electric power system includes some stages. Firstly, Power Plants as a source of power. Then, high voltage transmission lines are used to transfer power from power plants to power substations. power substations with their step-down transformers are installed for reducing the voltage to suitable levels to be distributed. As a last stage, Distribution systems are used to give the costumer his need of electricity. All these stages are as shown in figure (1).

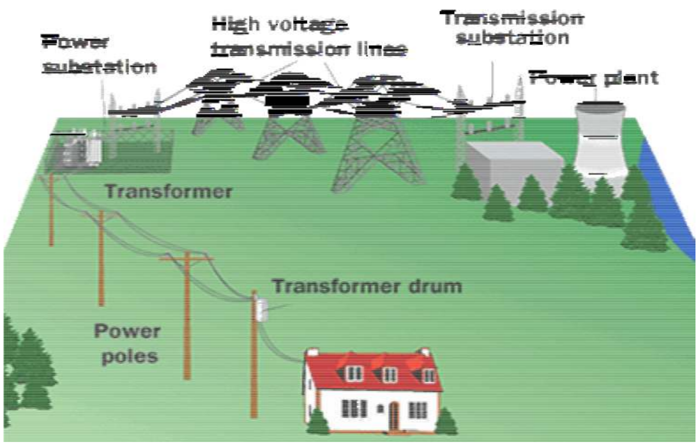


Figure 1. Complete Power System

2. Power system faults:

Power substations as a target of study consists of some elements which must be protected against different types of fault. These elements are Transmission Lines, Bus Bars, Power Transformers, Outgoing Feeders, and Bus Couplers. Before we go through different functions of protection relays, some of fault causes, fault effects, and fault types must be considered.

The main fault causes:

a) Fault Current
Healthy insulation in the equipment subjected to either transient over voltages of small-time duration due to switching and lightning strokes, direct or indirect. Failure of insulation may be happened, resulting in very high fault current. This current may be more than 10 times the rated or nominal current of the equipment.

b) Insulation Aging:
Aging of power equipment may cause breakdown of it even at normal power frequency voltage.

b) External Causes
External object such as bird, kite string, or tree branch are considered as external cause of fault. These objects may span one conductor and ground causing single line to ground fault (phase-earth) or span two conductors causing phase-phase fault

3. Fault effects:

The fault must be cleared as fast as possible. Many equipments may be destroyed if the fault is not cleared rapidly. The dangerous of the faults depends on the type of the fault, as example the three-phase short circuit is the most dangerous fault because the short circuit current is maximum. Some of the effects of short circuit current are listed here under.

a) Due to overheating and the mechanical forces developed by faults, electrical equipments such as bus bars, generators, transformers will be damaged
b) Negative sequence current arises from unsymmetrical faults will lead to overheating.

c) Voltage profiles may be reduced to unacceptable limits as a result of faults. A frequency drop may lead to instability
d) Due to overheating and the mechanical forces developed by faults, electrical equipments such as bus bars, generators, transformers will be damaged
e) Negative sequence current arises from unsymmetrical faults will lead to overheating.
f) Voltage profiles may be reduced to unacceptable limits as a result of faults. A frequency drop may lead to instability

4. Fault types:

The fault can be classified due to the NATURE of the fault to
a) Permanent
b) Transient

Or due to participated phases as
a) Phase-Earth
b) Phase-Phase
c) Phase-Phase-Earth
d) Three-Phase or Three-Phase-Earth

5. System protection components

Protection systems have three basic components:
1. Instrument transformers
2. Relays
3. Circuit breakers

Figure 2 shows a simple overcurrent protection schematic with: (1) one type of instrument transformer—the current transformer (CT), (2) an overcurrent relay (OC), and (3) a circuit breaker (CB) for a single-phase line.

The function of the CT is to reproduce in its secondary winding a current I’ that is proportional to the primary current I. The CT converts primary currents in the kiloamp range to secondary currents in the 0–5 ampere range for convenience of measurement, with the following advantages.

- Safety: Instrument transformers provide electrical isolation from the
- power system so that personnel working with relays will work in a safer
- environment.
- Economy: Lower-level relay inputs enable relays to be smaller, simpler,
- and less expensive.
- Accuracy: Instrument transformers accurately reproduce power system
- currents and voltages over wide operating ranges.

The function of the relay is to discriminate between normal operation and fault conditions. The OC relay in Figure 2 has an operating coil, which is connected to the CT secondary winding, and a set of contacts. When |I'| exceeds a specified ‘‘pickup’’ value, the operating coil causes the normally open contacts to close. When the relay contacts close, the trip coil of the circuit breaker is energized, which then causes the circuit breaker to open.

Note that the circuit breaker does not open until its operating coil is energized, either manually or by relay operation. Based on information from instrument transformers, a decision is made and ‘‘relayed’’ to the trip coil of the breaker, which actually opens the power circuit—hence the name relay.

System-protection components have the following design criteria:

- Reliability: Operate dependably when fault conditions occur, even after remaining idle for months or years.

Failure to do so may result in costly damages.

- Selectivity: Avoid unnecessary, false trips.
- Speed: Operate rapidly to minimize fault duration and equipment damage. Any intentional time delays should be precise.
- Economy: Provide maximum protection at minimum cost.
- Simplicity: Minimize protection equipment and circuitry.

Since it is impossible to satisfy all these criteria simultaneously, compromises must be made in system protection.

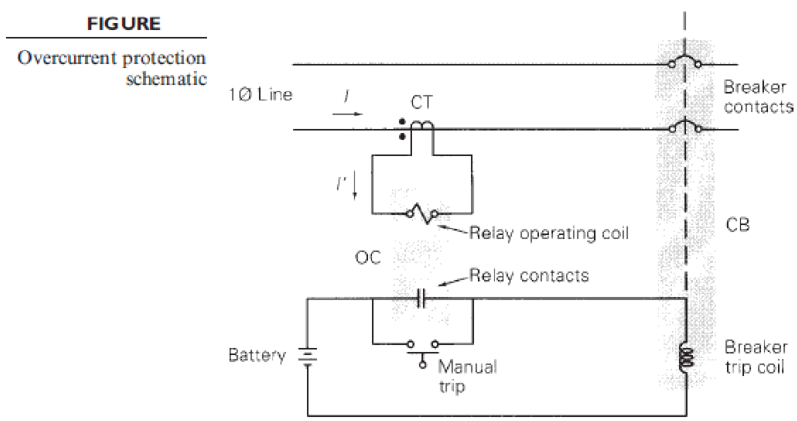


Figure 2. Overcurrent protection schematic

3) Chapter 2: Instrument Transformers

High voltage network components are subject to high voltage magnitudes (220 kV, 66 kV or at least 11 kV) and hundreds of amperes are passing through them. Instrument transformers are used to reduce the values of volts and current to standard secondary values which are (100 v or 110 v) and (1 or 5) amperes. These values are suitable for protection and measuring relays. Advantage of using instrument transformers is isolating the current and voltage coils of relays from high voltages of the power system.

1. Basic idea of Instrument Transformer

Instrument transformer is similar to power transformer in the idea of work which depends on, when alternating current (AC) follow through primary winding of the transformer, this currents creates a magnetic-motive force (M.M.F.) causing an alternating flux in the core, which is translated as a current in the secondary winding of the transformer. This study is concentrated on the practical view of current transformer, differential between metering and protection cores of current transformer, stare and open delta of Voltage transformer.

2.Current Transformer:

Current transformer consists at least of two secondary cores. The first core is usually designed for measuring, the second (and third…if exist) is (are) used for protection. The secondary of current transformers are almost connected in star.

The stare point of each secondary core must be earthed. All relays of each core are connected in series. Figure (2) shows the secondary connection of one secondary core of a current transformer and the relays connected with it.

Note: Due to voltage transformation between primary and secondary winding of current transformer, high voltage may be induced on the secondary winding. So, the secondary core must be earthed to prevent secondary leads and relays from high voltage.

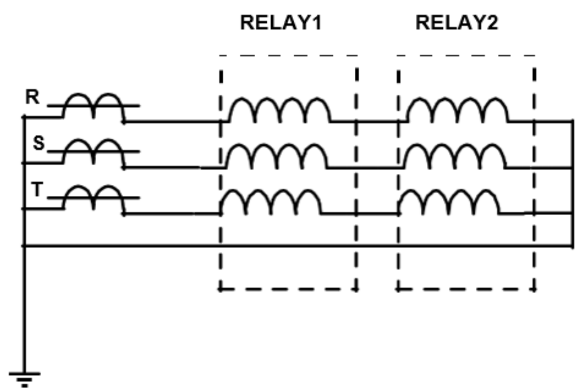


Figure 2: Two relays connected in series at the same core

3. Measuring and Protection Cores:

The measuring core of current transformer is connected to current coils of Ammeters, Wattmeters, Watt-hour meters, Var-Meters, and Var-Hour-Metes. The zone of work of all these relays below the rated of secondary of current transformer.

The measuring cores must have high to accurate monitor of the system quantities accuracy in the range of load levels. In fault conditions, current is very high and may reach 20 times the rated value. So, measuring core must be saturated to avoid the damage of measuring instruments.

Protection cores are designed to work at high levels of current (at fault). The accuracy of these cores may be less comparing with measuring cores. The saturation level of these cores is very higher than measuring cores. Magnetization curve of current transformer with measuring and protection cores is shown in figure (3), and different regions of magnetization curve is shown in figure (4).

Note: The knee point can be defined as the point at which a 10% increase flux density causes 50% increase in exciting ampere -turns.

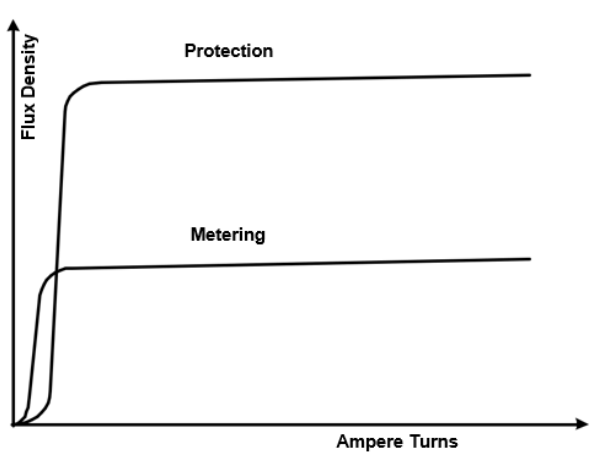


Figure 3: Protection and Metering Cores

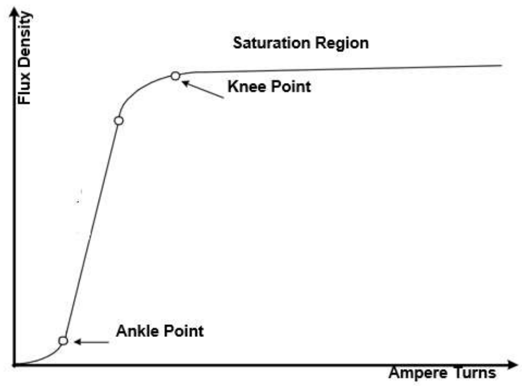


Figure 4: Different Regions of Magnetization Curve

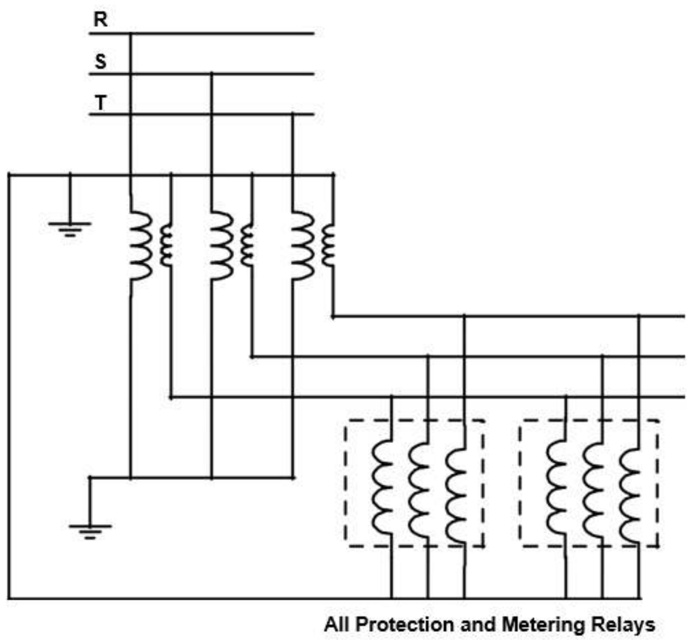
4. Open Circuit Current Transformer:

If by mistake, secondary is open circuited. The voltage across the secondary rises to very high level. The process results in zero secondary current. Some problems rise from the open circuit of current transformer is:

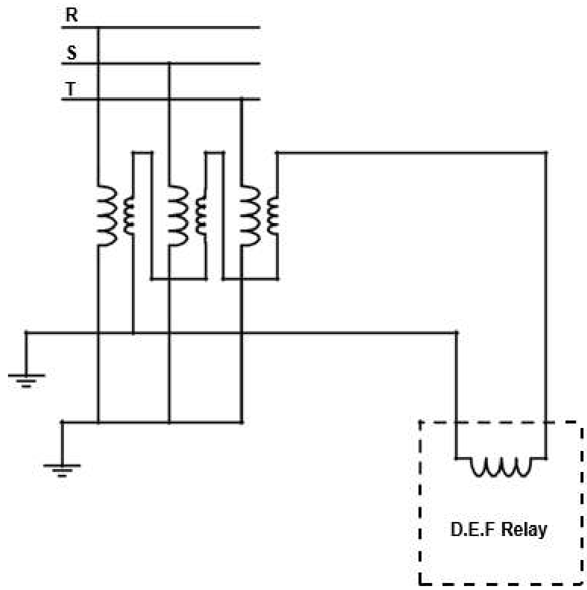
- The primary winding and the core are over heated. This heat may be sufficient to damage the current transformer.
- High voltage induced between secondary terminals of current transformer is very dangers on the persons and the relays connected with it.

5. Voltage Transformer:

Voltage transformer is often consisting of two cores. The first core is connected in star, and the stare point must be earthed. The second core is connected as open delta. Voltage coils of protection relays and measuring meters are connected in parallel with the star core. Open delta core is used for directional earth fault relay. Connection of stare and open delta core with protection relays and measuring meters are shown in Figure (5), and Figure (6) respectively.



Star Connection of Voltage Transformer**Figure 5:**



Open Delta Connection of Voltage Transformer**Figure 6:**

6. DC System:

Because protective equipment must be ready to clear faults all times. The reliability will not achieve without an absolutely reliable source of supply to operate the trip coils of circuit breakers and all auxiliary relays participation in the tripping process.

To reach this reliability, Battery with nominal voltage of 110 or 220 V is installed. This battery is charged by one of two charges. One of the two charges is connected to the battery and the other is stand by to be connected if the first charger is disconnected. The load is connected to battery and the charger by dc buses. In this situation, the charger acts as a source of dc to feed the load and charge the battery. If the AC supply of the charger is switched, then the charger is out of service and the battery acts as a source of DC to feed the DC load. Connection of charger, battery, and loads as shown in Figure 7.

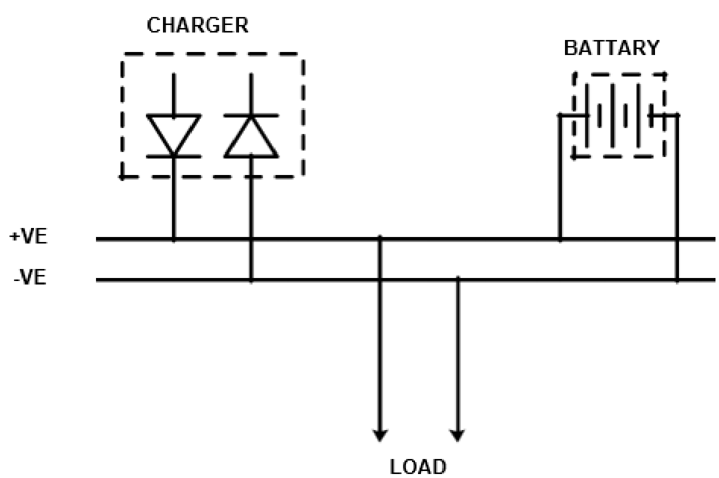


Figure 7. DC System of a Substation

7. DC-Earth Fault Alarm Device

Three resistors are used in this device as shown in Figure (8). R1, R2 can be replaced by two lamps (L1, L2). If there is an earth leakage on the positive side then light of L1 will be decreased according to the resistance of earth path and will be off in the case of soil earth path. In the opposite, the light of L2 will be increased.

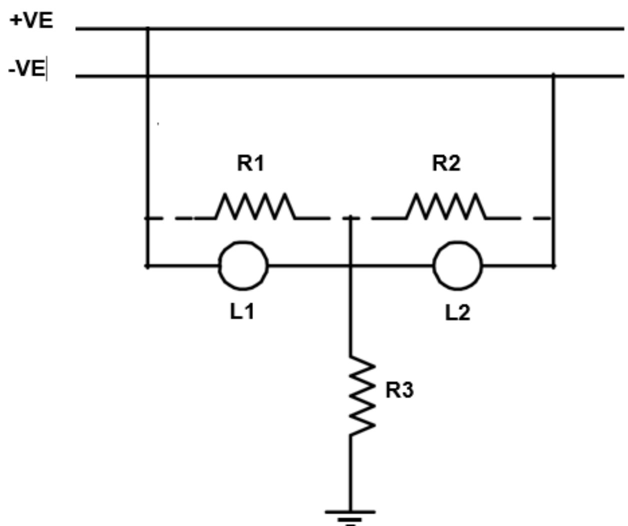


Figure 8. DC-Earth Fault Alarm Device

8. Schematic Representation of Instrument Transformers:

There are two basic types of instrument transformers: voltage transformers (VTs), formerly called potential transformers (PTs), and current transformers (CTs). Figure 9 shows a schematic representation for the VT and CT.

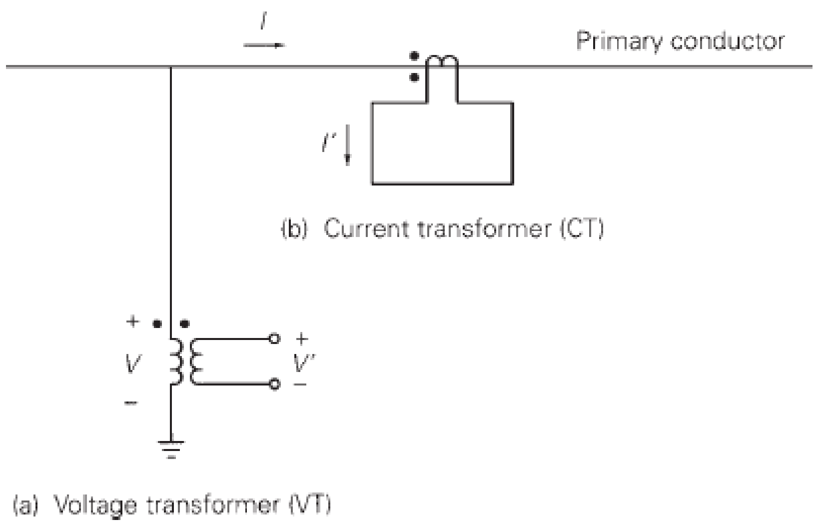


Figure 9. VT and CT schematic

The transformer primary is connected to or into the power system and is insulated for the power system voltage. The VT reduces the primary voltage and the CT reduces the primary current to much lower, standardized levels suitable for operation of relays. For system-protection purposes, VTs are generally considered to be sufficiently accurate. Therefore, the VT is usually modeled as an ideal transformer here

$$V' = (1/n)V$$

V' is a scaled-down representation of V and is in phase with V. A standard VT secondary voltage rating is 115 V (line-to-line). Standard VT ratios are given in the following Table:

TABLE	Voltage Ratios						
Standard VT ratios	1:1	2:1	2.5:1	4:1	5:1	20:1	40:1
	60:1	100:1	200:1	300:1	400:1	600:1	800:1
	1000:1	2000:1	3000:1	4500:1			

Ideally, the VT secondary is connected to a voltage-sensing device with infinite impedance, such that the entire VT secondary voltage is across the sensing device. In practice, the secondary voltage divides across the high impedance sensing device and the VT series leakage impedances. VT leakage impedances are kept low in order to minimize voltage drops and phase-angle differences from primary to secondary.

The primary winding of a current transformer usually consists of a single turn, obtained by running the power system's primary conductor through the CT core. The normal current rating of CT secondaries is standardized at 5 A in the United States, whereas 1 A is standard in Europe and some other regions. Currents of 10 to 20 times (or greater) normal rating often occur in CT windings for a few cycles during short circuits. Standard CT ratios are given in the following Table:

TABLE	Current Ratios						
Standard CT ratios	50:5	100:5	150:5	200:5	250:5	300:5	400:5
	450:5	500:5	600:5	800:5	900:5	1000:5	1200:5
	1500:5	1600:5	2000:5	2400:5	2500:5	3000:5	3200:5
	4000:5	5000:5	6000:5				

Ideally, the CT secondary is connected to a current-sensing device with zero impedance, such that the entire CT secondary current flows through the sensing device. In practice, the secondary current divides, with most flowing through the low-impedance sensing device and some flowing through the CT shunt excitation impedance. CT excitation impedance is kept high in order to minimize excitation current.