

Module 1 : Fundamentals of Power System Protection

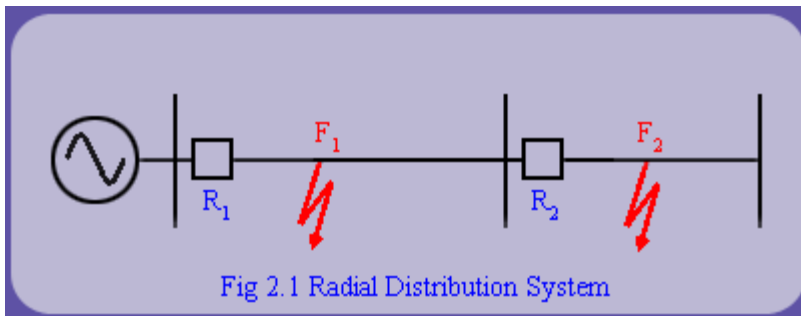
Lecture 2 : Protection Paradigms - Apparatus Protection

Objectives

In this lecture we will introduce the following:

- Principle of overcurrent protection.
- Principle of directional overcurrent protection.
- Principle of distance protection.
- Principle of differential protection.
- For simplicity in explaining the key ideas, we consider three phase bolted faults. Generalization of different fault types will be discussed in subsequent lectures.

2.1 Overcurrent Protection

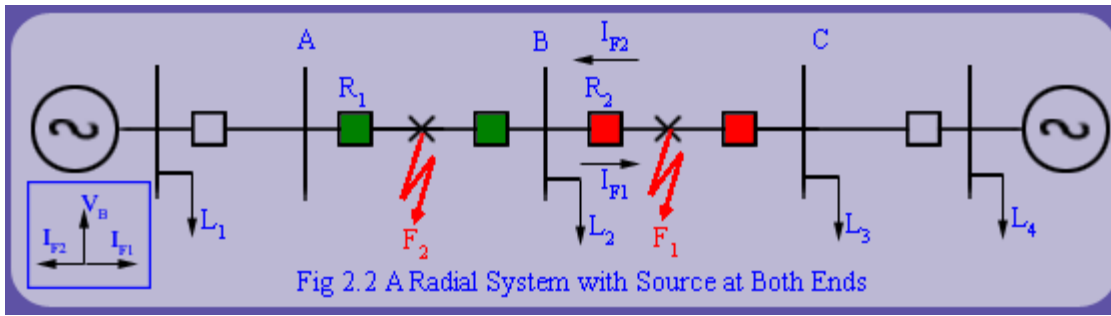


This scheme is based on the intuition that, faults typically short circuits, lead to currents much above the load current. We can call them as overcurrents. Over current relaying and fuse protection uses the principle that when the current exceeds a predetermined value, it indicates presence of a fault (short circuit). This protection scheme finds usage in radial distribution systems with a single source. It is quite simple to implement.

Fig 2.1 shows a radial distribution system with a single source. The fault current is fed from only one end of the feeder. For this system it can be observed that:

- To relay R_1 , both downstream faults F_1 and F_2 are visible i.e. I_{F1} as well as I_{F2} pass through CT of R_1 .
- To relay R_2 , fault F_1 , an upstream fault is not seen, only F_2 is seen. This is because no component of I_{F1} passes through CT of R_2 . Thus, selectivity is achieved naturally. Relaying decision is based solely on the magnitude of fault current. Such a protection scheme is said to be non-directional.

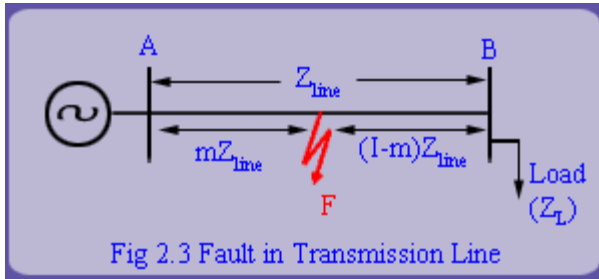
2.2 Directional Overcurrent Protection



In contrast, there can be situations where for the purpose of selectivity, phase angle information (always relative to a reference phasor) may be required. Fig 2.2 shows such a case for a radial system with source at both ends. Consequently, fault is fed from both the ends of the feeder. To interrupt the fault current, relays at both ends of the feeder are required.

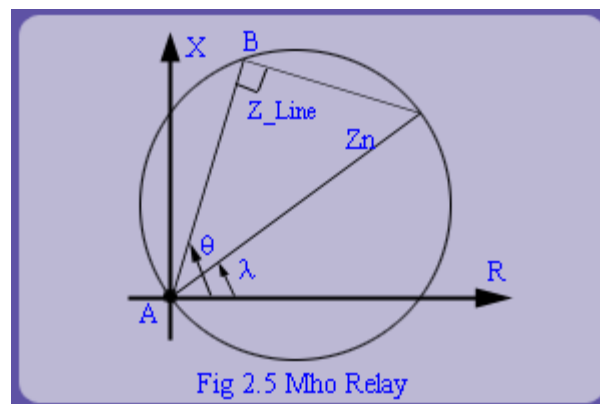
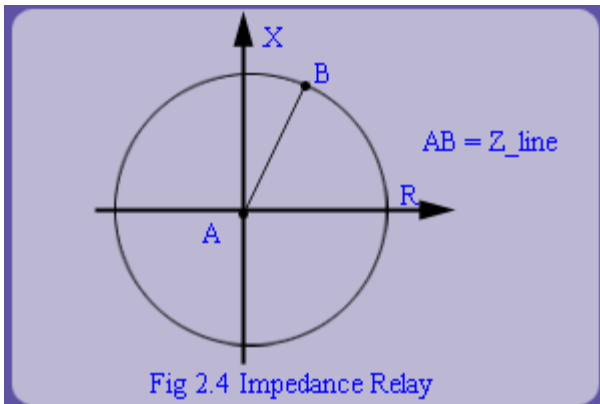
In this case, from the magnitude of the current seen by the relay R_2 , it is not possible to distinguish whether the fault is in the section AB or BC. Since faults in section AB are not in its jurisdiction, it should not trip. To obtain selectivity, a directional overcurrent relay is required. It uses both magnitude of current and phase angle information for decision making. It is commonly used in subtransmission networks where ring mains are used.

2.3 Distance Protection



Consider a simple radial system, which is fed from a single source. Let us measure the apparent impedance (V/I) at the sending end. For the unloaded system, $I = 0$, and the apparent impedance seen by the relay is infinite. As the system is loaded, the apparent impedance reduces to some finite value ($Z_L + Z_{line}$) where Z_L is the load impedance and Z_{line} is the line impedance. In presence of a fault at a per-unit distance 'm', the impedance seen by the relay drops to a mZ_{line} as shown in fig 2.3.

The basic principle of distance relay is that the apparent impedance seen by the relay, which is defined as the ratio of phase voltage to line current of a transmission line (Z_{app}), reduces drastically in the presence of a line fault. A distance relay compares this ratio with the positive sequence impedance (Z_1) of the transmission line. If the fraction Z_{app}/Z_1 is less than unity, it indicates a fault. This ratio also indicates the distance of the fault from the relay. Because, impedance is a complex number, the distance protection is inherently directional. The first quadrant is the forward direction i.e. impedance of the transmission line to be protected lies in this quadrant. However, if only magnitude information is used, non-directional impedance relay results. Fig 2.4 and 2.5 shows a characteristic of an impedance relay and 'mho relay' both belonging to this class. The impedance relay trips if the magnitude of the impedance is within the circular region. Since, the circle spans all the quadrants, it leads to non-directional protection scheme. In contrast, the mho relay which covers primarily the first quadrant is directional in nature.



Thus, the trip law for the impedance relay can be written as follows:

$$|Z_{app}| = \frac{|V_R|}{|I_R|} < |Z_{set}|, \text{ then trip; else restrain. While impedance relay has only one design parameter, } Z_{set};$$

'mho relay' has two design parameters Z_n, λ . The trip law for mho relay is given by if

$|Z_{app}| < |Z_n| \cos(\theta - \lambda)$, then trip; else restrain. As shown in the fig 2.5 ' θ ' is the angle of transmission line. Based upon legacy of electromechanical relays ' λ ' is also called 'torque angle'.

2.3 Distance Protection

2.3.1 Example

1. (a) Find out the value of Z_n for a mho relay with torque angle 75° which has to give 100% protection to a 50 km long 110kV transmission line with impedance 0.8Ω per km and angle 80° .

Ans: The two design parameters of a mho relay are Z_n and λ . Here the torque angle, λ of the relay has been selected as 75° .

The transmission line impedance Z_{Line} as on primary = 0.8×50
 $= 40\Omega$

$$Z_{Line} \text{ (secondary)} = Z_{Line} \text{ (primary)} \times \frac{R_c}{R_v}$$

where R_c , CT ratio = 200
 R_v , VT ratio = 1000

$$Z_{Line} \text{ (Secondary)} = 40 \times \frac{200}{1000} = 8\Omega$$

$Z_{Line} = Z_n \cos(\theta - \lambda)$ where θ = angle of transmission line

$$Z_n = \frac{Z_{Line}}{\cos(\theta - \lambda)}$$

$$= \frac{8}{\cos(80 - 75)} = \frac{8}{\cos 5} = 8.03\Omega, \text{ this value is to be set on the mho relay.}$$

- (b) If the maximum load on this line is 1000A at 30° lagging, is there any possibility of relay tripping on load? CT ratio is 1000:5

Ans: Maximum Load current $I_{load} = 1000A$

$$V_{Line} = 110 \times 10^3 V$$

$$Z_{load} = \frac{V_{Line}}{\sqrt{3} \times I_{load}} = \frac{110 \times 10^3}{\sqrt{3} \times 1000} = 63.5\Omega$$

$$Z_{load} \text{ Secondary} = 63.5 \times \frac{R_c}{R_v} = 63.5 \times \frac{200}{1000} = 12.7\Omega$$

Since this value will not fall within the operating circle, the mho relay will not trip for this load.

2.4 Principle of Differential Protection

Differential protection is based on the fact that any fault within an electrical equipment would cause the current entering it, to be different, from the current leaving it. Thus by comparing the two currents either in magnitude or in phase or both we can determine a fault and issue a trip decision if the difference exceeds a predetermined set value.

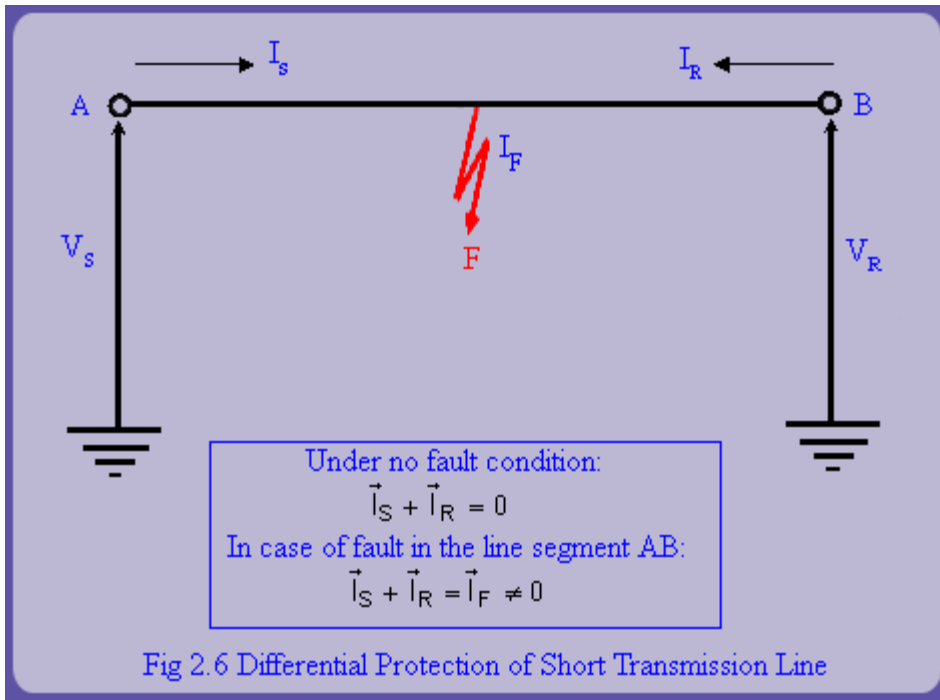
2.4.1 Differential Protection for Transmission Line

Fig 2.6 shows a short transmission line in which shunt charging can be neglected. Then under no fault condition, phasor sum of currents entering the device is zero i.e.

$$\vec{I}_S + \vec{I}_R = 0$$

Thus, we can say that differential current under no fault condition is zero.

However in case of fault in the line segment AB, we get

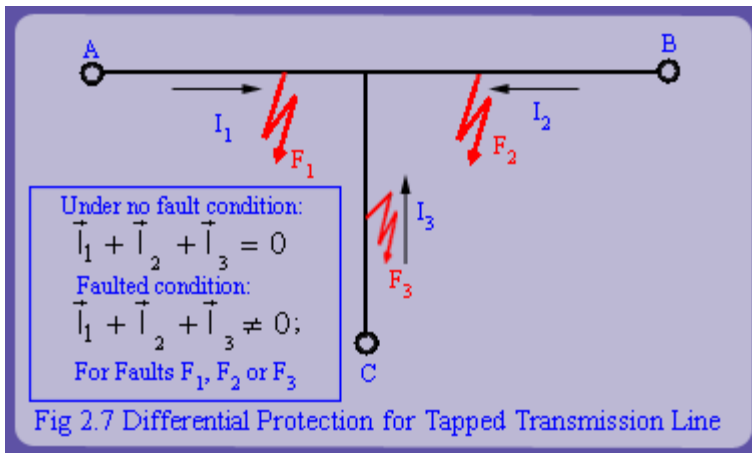


This principle of checking the differential current is known as a differential protection scheme. In case of transmission line, implementation of differential protection requires a communication channel to transmit current values to the other end. It can be used for short feeders and a specific implementation is known as pilot wire protection. Differential protection tends to be extremely accurate. Its zone is clearly demarcated by the CTs which provide the boundary.

2.4 Principle of Differential Protection

2.4.1 Differential Protection for Transmission Line (Tapped Line)

Differential protection can be used for tapped lines (multiterminal lines) where boundary conditions are defined as follows:



Under no fault condition:

$$\vec{I}_1 + \vec{I}_2 + \vec{I}_3 = 0$$

Faulted condition:

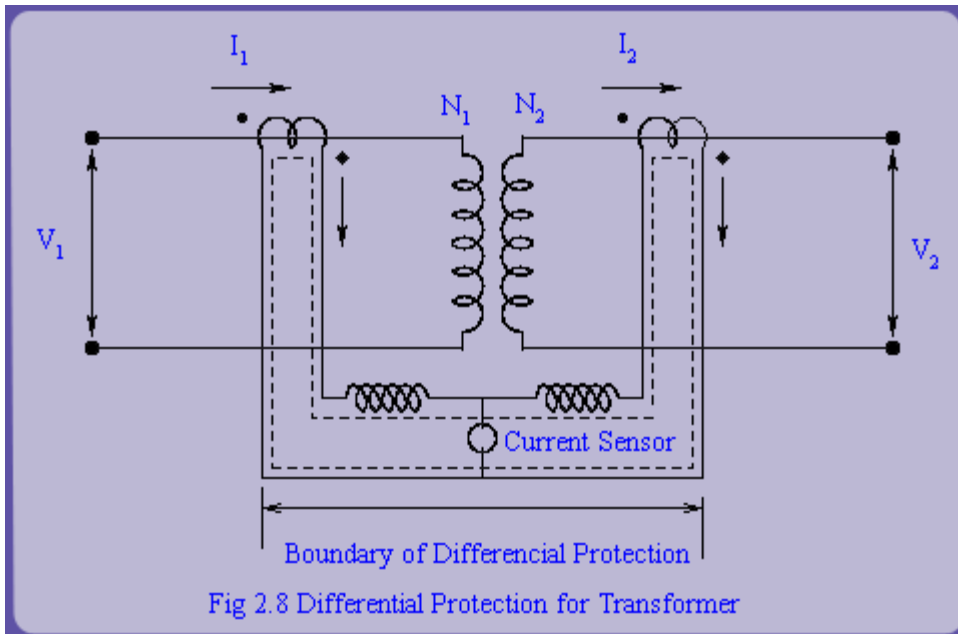
$$\vec{I}_1 + \vec{I}_2 + \vec{I}_3 \neq 0$$

2.4 Principle of Differential Protection

Differential protection for detecting faults is an attractive option when both ends of the apparatus are physically located near each other. e.g. on a transformer, a generator or a bus bar.

2.4.2 Differential Protection for Transformer

Consider an ideal transformer with the CT connections, as shown in fig 2.8. To illustrate the principle let us consider that current rating of primary winding is 100A and secondary winding is



1000A. Then if we use 100:5 and 1000:5 CT on the primary and secondary winding, then under normal (no fault) operating conditions the scaled CT currents will match in magnitudes. By connections the primary and secondary CTs with due care to the dots (polarity markings), a circulating current can be set up as shown by dotted line.

No current will flow through the branch having overcurrent current relay because it will result in violation of KCL. Now if an internal fault occurs within the device like interturn short etc., then the normal mmf balance is upset i.e. $N_1 I_1 \neq N_2 I_2$. Under this condition, the CT secondary currents of primary and secondary side CTs will not match. The resulting differential current will flow through overcurrent relay. If the pick up setting of overcurrent relay is close to zero, it will immediately pick up and initiate the trip decision.

In practice, the transformer is not ideal. Consequently, even if $I_2 = 0, I_1 \neq 0$, it is the magnetization current or (no load) current. Thus, a differential current always flows through the overcurrent relay. Therefore overcurrent relay pick up is adjusted above the no load current value. Consequently, minute faults below no load current value cannot be detected. This compromises sensitivity.

2.4 Principle of Differential Protection

2.4.3 Differential Protection for Busbar

Ideally, differential protection is the solution for the bus-bar protection.

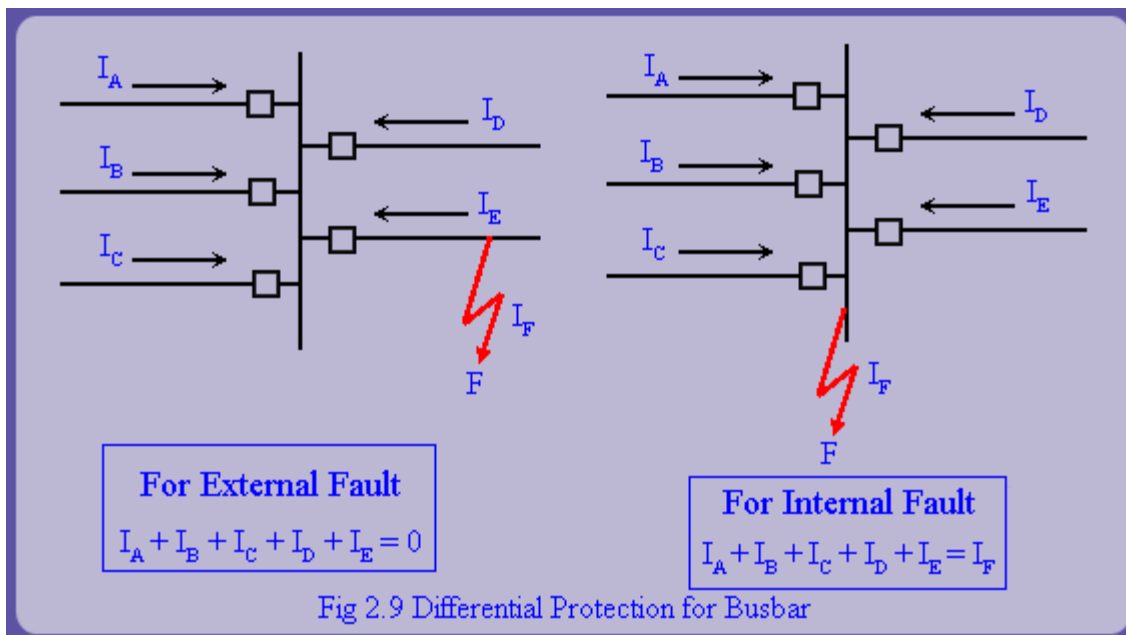


Figure 2.8 illustrates the basic idea. If the fault is external to the bus, it can be seen that algebraic sum of the currents entering the bus is zero.

$$\vec{I}_A + \vec{I}_B + \vec{I}_C + \vec{I}_D + \vec{I}_E = 0$$

On the other hand, if fault is on the bus (internal fault), this sum is not zero.

$$\vec{I}_A + \vec{I}_B + \vec{I}_C + \vec{I}_D + \vec{I}_E = \vec{I}_F$$

Thus, differential protection can be used to protect a bus.

Review Questions

1. Why is phase angle information required to protect a radial system with source at both ends?
2. Discuss the basic principle of distance protection.
3. How is differential protection scheme used in the following:
 - (1) Transmission line protection.
 - (2) Transformer protection.
 - (3) Busbar protection.
4. For the tapped line (fig 2.6), no relays are provided at the tapping point. Can you explain reasons for the same?

Recap

In this lecture we have learnt the following:

- Principle of overcurrent protection.
- Principle of distance protection.
- Principle of directional overcurrent protection.
- Differential protection.
- Applications to apparatus protection.

