Power System Protection

EE454

(Chapter 7 started)

Lecture file # 6b
ODL Week (Dec. 7 – Dec. 11)
for lecture on 11^{th} Dec.

- **Note:**

The materials in this presentation are only for the use of students enrolled in this course in the specific campus; these materials are for purposes associated with this course and may not be further disseminated or retained after expiry of the course.

Session No.	Content of the Lecture presentation (from Ch#7 of PS Relaying)	
3 of the ODL Week (Dec. 7 – Dec. 11)	Slide 4 - 13	Phase fault protection for rotating machinery – use of simple and percentage differential relay.

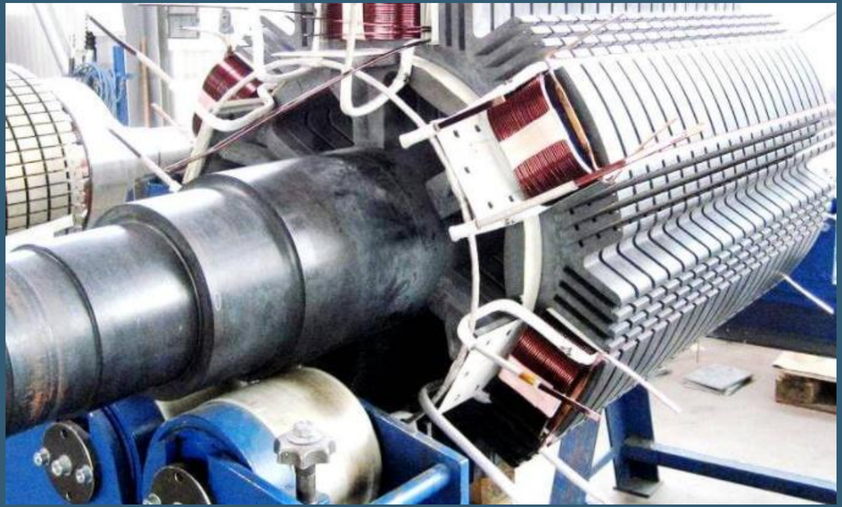

بسم الله الرحمن الرحيم

CLO3	Evaluate the relay settings for the coordination of overcurrent and distance relays in distribution and transmission lines respectively.	PLO03	Cognitive	5. Evaluate
CLO4	Design appropriate protection schemes for various components like transformers, rotating machinery, bus-bars, shunt and series compensating devices.	PLO04	Cognitive	6. Create

7

Rotating machinery protection

The protection of rotating equipment involves the consideration of more possible failures or abnormal operating conditions than any other system element. Although the frequency of failure, particularly for generators and large motors, is relatively low, the consequences in cost and system performance are often very serious. Paradoxically, despite many failure modes that are possible, the application principles of the protection are relatively simple. There are none of the complications requiring a pilot scheme. Those failures involving short circuits are usually detected by some type of differential or overcurrent relay.



Some of the abnormal conditions that must be dealt with are the following.

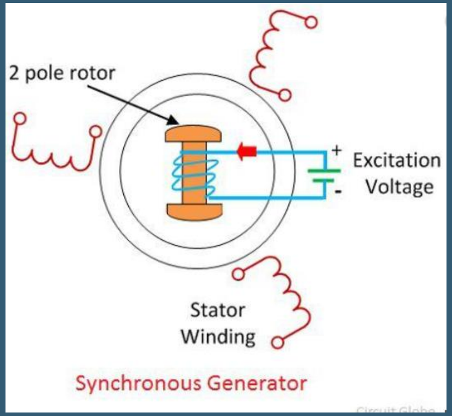
1. Winding faults:
   stator – phase and ground fault
2. Overload
3. Overspeed
4. Abnormal voltages and frequencies.

For generators we must consider the following.

5. Underexcitation
6. Motoring and startup.

For motors we are concerned with the following.

7. Stalling (locked rotor)
8. Single phase
9. Loss of excitation (synchronous motors).



7.2 Stator faults

7.2.1 Phase fault protection

For short circuits in a stator winding, it is standard practice to use differential protection on generators rated 1000 kVA or higher and on motors rated 1500 hp or larger or rated 5 kV and above.

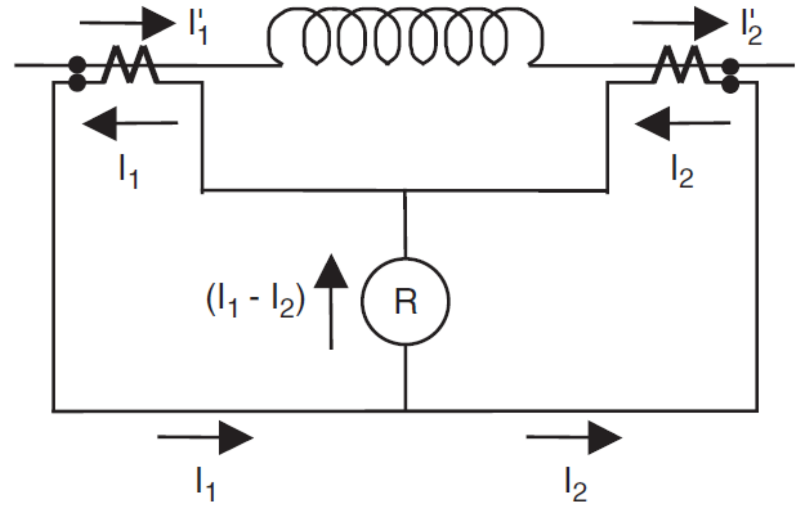


Figure 7.1 Generator differential connection with overcurrent relay

Example 7.1

Consider the system shown in Figure 7.2 which represents a generator prior to being synchronized to the system. The generator is protected by an overcurrent relay, 87,* connected in a differential circuit as shown. The maximum load is $125\,000/(\sqrt{3} \times 15.5) = 4656.19$ A. For this maximum load select a 5000:5 (1000:1) CT ratio. This results in a secondary current of 4.66 A at full load. Before the unit is synchronized, a three-phase fault at either F_1 or F_2 is $(V_{pu}/x''_d) \times I_{f1}$ or $(1.0/0.2) \times 4656.19 = 23280.95$ primary amperes or 23.28 secondary amperes.

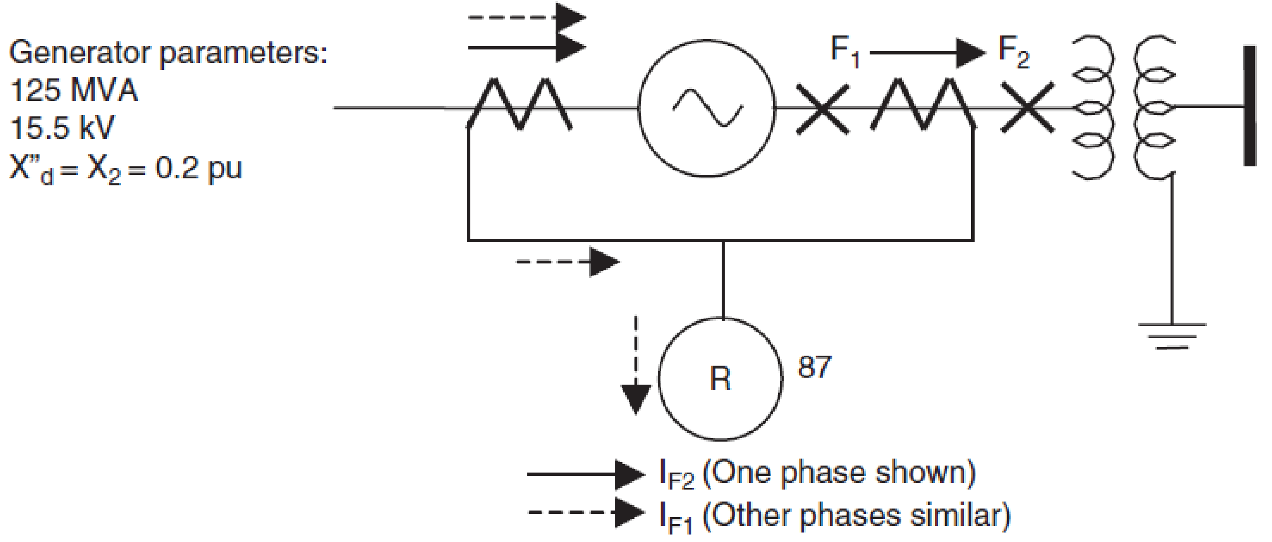


Figure 7.2 One-line diagram for Example 7.1

For the external fault at F_2, 23.28 A flow through both CT secondary circuits and nothing flows in the overcurrent relay.

For the internal fault at F_1, 23.28 A flow through only one CT secondary and the operating coil of 87.

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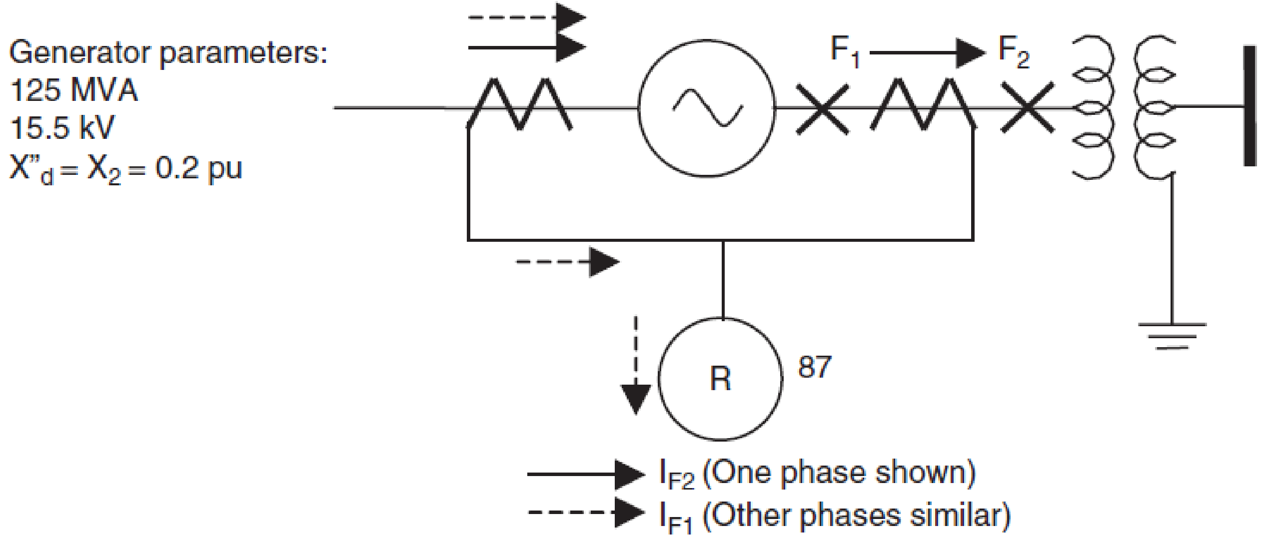

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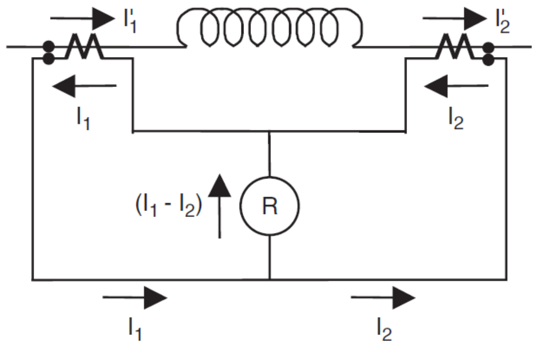

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For the internal fault at F_1, 23.28 A flow through only one CT secondary and the operating coil of 87.

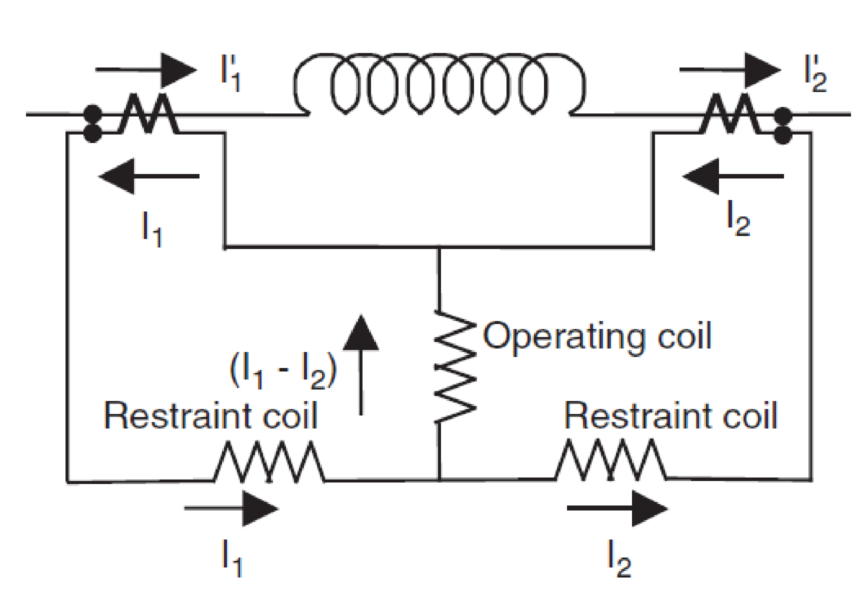
Percentage Differential Relay

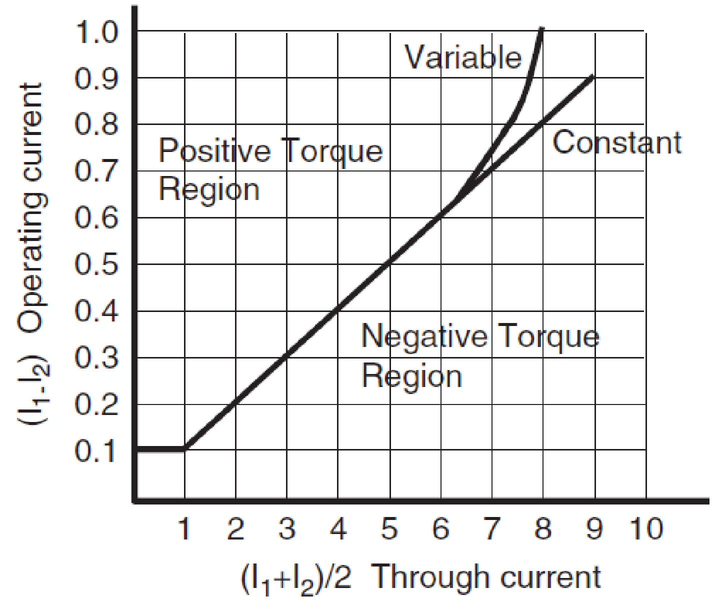
In simple differential relay;

the CTs will not always give the same secondary current for the same primary current, even if the CTs are commercially identical. The difference in secondary current, even under steady-state load conditions, can be caused by the variations in manufacturing tolerances and in the difference in secondary loading, i.e. unequal lengths of leads to the relay, unequal burdens of meters and instruments that may be connected in one or both of the secondaries.

To solve this problem, we make percentage differential relay :-

the differential current required to operate this relay can be either a constant or a variable percentage of the current in the restraint windings. The constant percentage differential relay operates, as its name implies, on a constant percentage of the through or total restraint current. For instance, a relay with a 10 % characteristic would require at least 2.0 A in the operating winding with 20 A through-current flowing in both restraint windings.





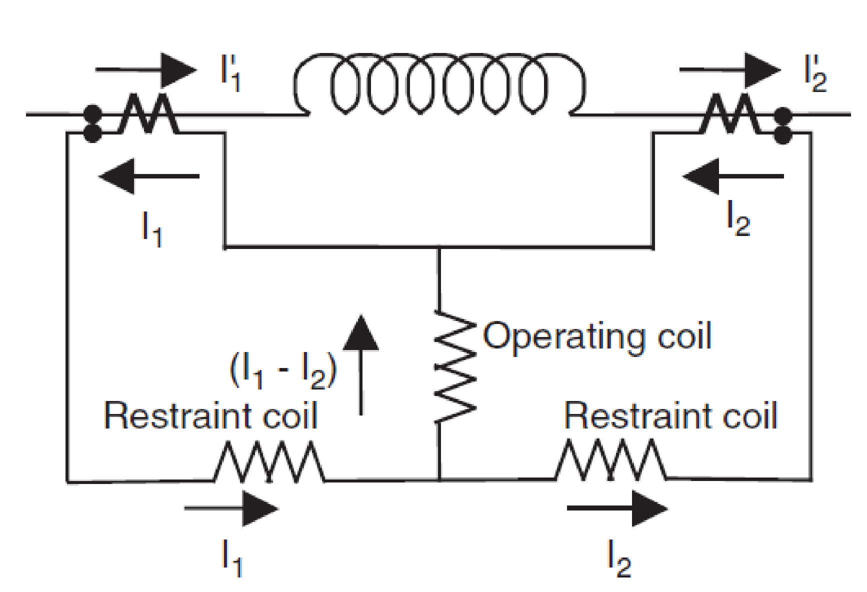
Percentage Differential Relay

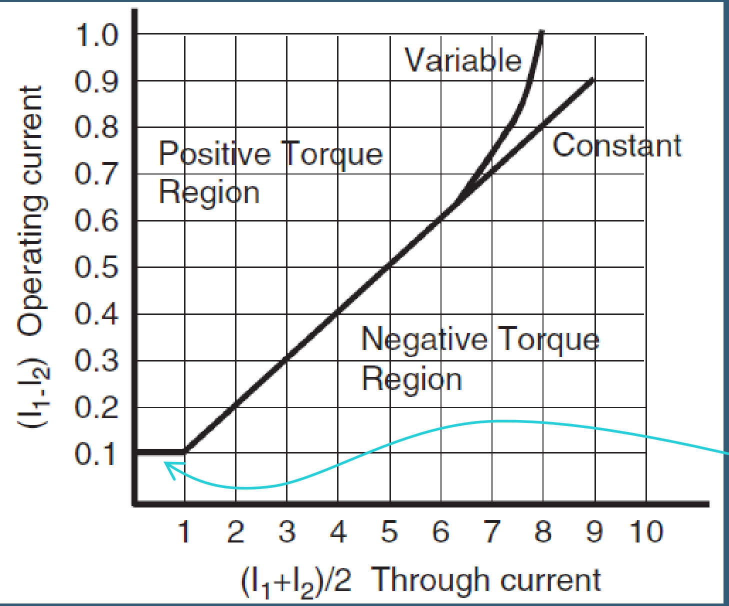
In simple differential relay;

the CTs will not always give the same secondary current for the same primary current, even if the CTs are commercially identical. The difference in secondary current, even under steady-state load conditions, can be caused by the variations in manufacturing tolerances and in the difference in secondary loading, i.e. unequal lengths of leads to the relay, unequal burdens of meters and instruments that may be connected in one or both of the secondaries.

To solve this problem, we make percentage differential relay :-

the differential current required to operate this relay can be either a constant or a variable percentage of the current in the restraint windings. The constant percentage differential relay operates, as its name implies, on a constant percentage of the through or total restraint current. For instance, a relay with a 10 % characteristic would require at least 2.0 A in the operating winding with 20 A through-current flowing in both restraint windings.

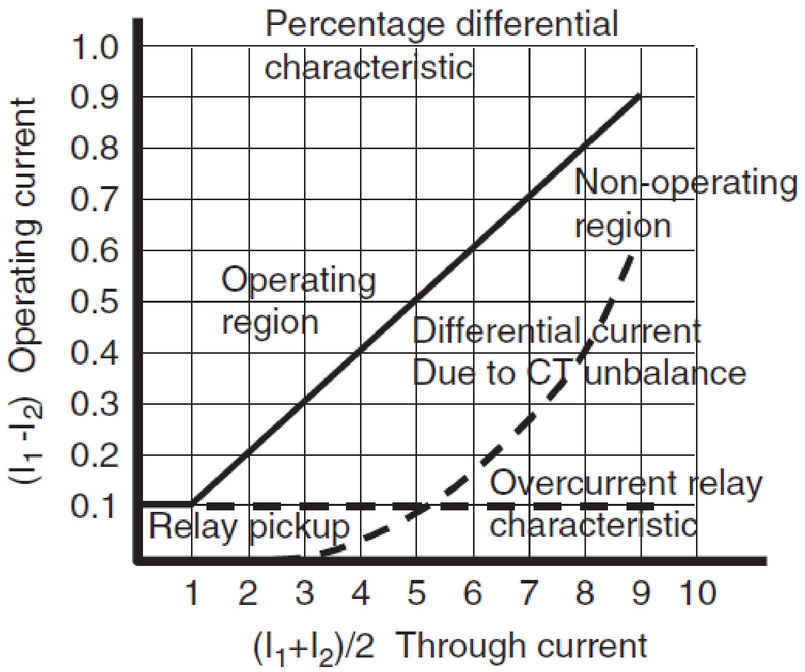




Apparently, this is the minimum pick up of the relay equal to 0.1 A

Example 7.2

Figure 7.5 shows the difference in the operating characteristics of the generator differential when using an overcurrent relay as shown in Figure 7.1 or a constant percentage differential relay as shown in Figure 7.3. Also shown is a typical plot of the error current due to CT unbalance caused by different burdens or saturation. Both relays are set for the same pickup of 0.1 A. It is clear that a through-current greater than 4.5 A will exceed 0.1 A in the operating coil and will trip the overcurrent relay incorrectly, whereas the entire error current plot lies in the nonoperating region of the differential relay, and there would be no tendency for the percentage differential relay to operate.



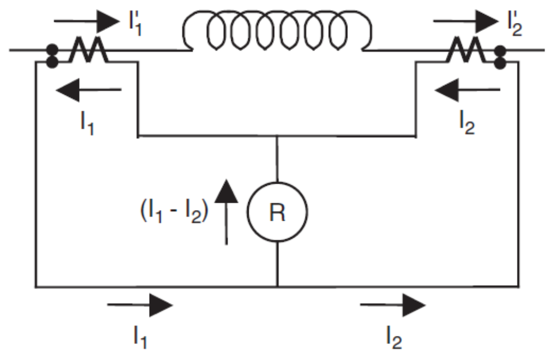


Figure 7.1 Generator differential connection with overcurrent relay

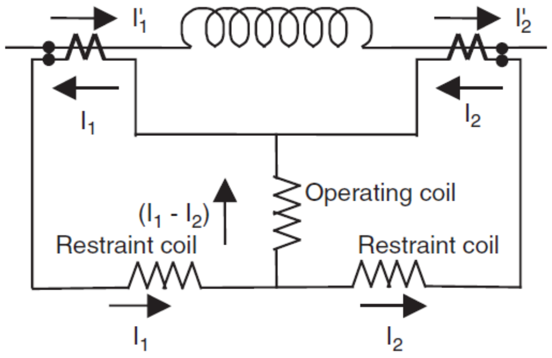


Figure 7.3 Generator differential using percentage differential relay

Slide from PSA – ODL week 7 lecture.

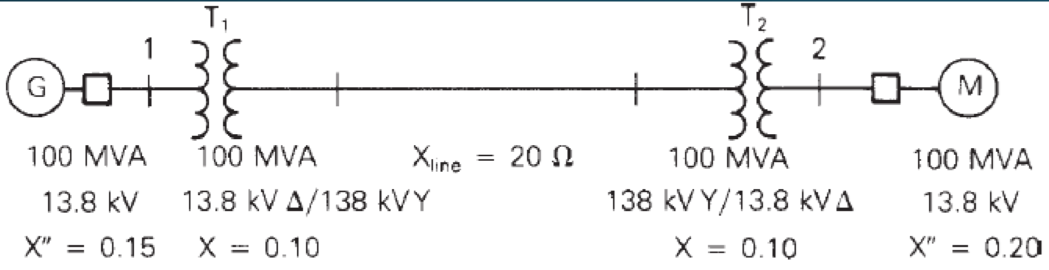


FIGURE 7.3

Single-line diagram of a synchronous generator feeding a synchronous motor

$$I''_F = \frac{V_F}{Z_{th}}$$

$$Z_{Th} = jX_{Th} = j\frac{(0.15)(0.505)}{(0.15 + 0.505)} = j0.11565 \quad \text{per unit}$$

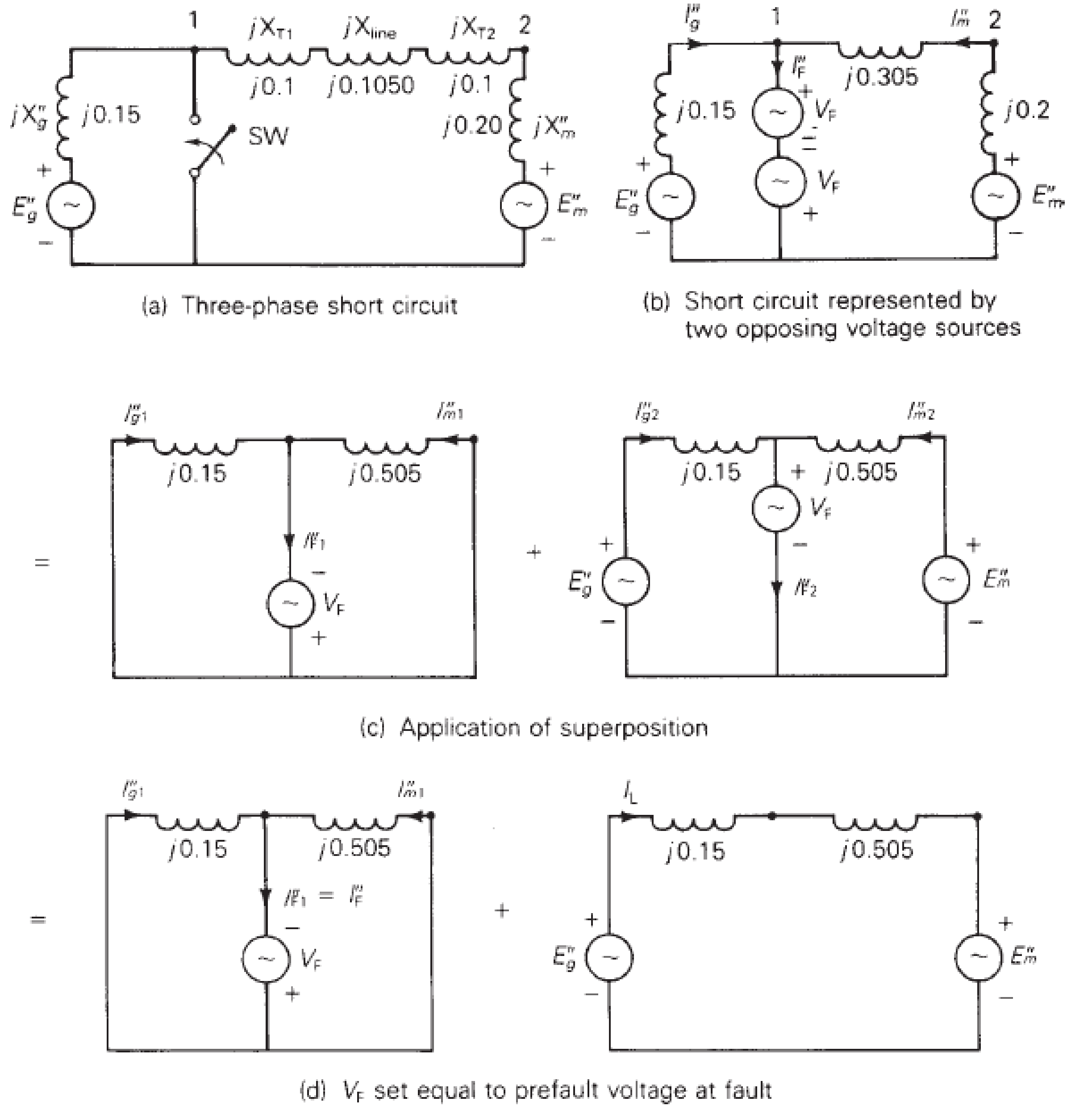


FIGURE 7.4 Application of superposition to a power system three-phase short circuit

Example 7.3

Consider the system and the associated positive sequence network shown in Figure 7.6 when the unit is synchronized to the system. The generator is protected by a percentage differential relay (87) set for a minimum pickup of 0.2 A. Full load current is $125\,000/(\sqrt{3} \times 15.5) = 4656.19$ A. Select a CT ratio of 5000:5 (1000:1). The per-unit reactances on a 100 000 kVA, 15.5 kV base are

$$x''_d = 0.2 \times (100/125) = 0.16 \text{ pu}$$

$$x_t = 0.15 \times (100/150) = 0.1 \text{ pu}$$

$$x_{sys} = 0.025 \text{ pu}$$

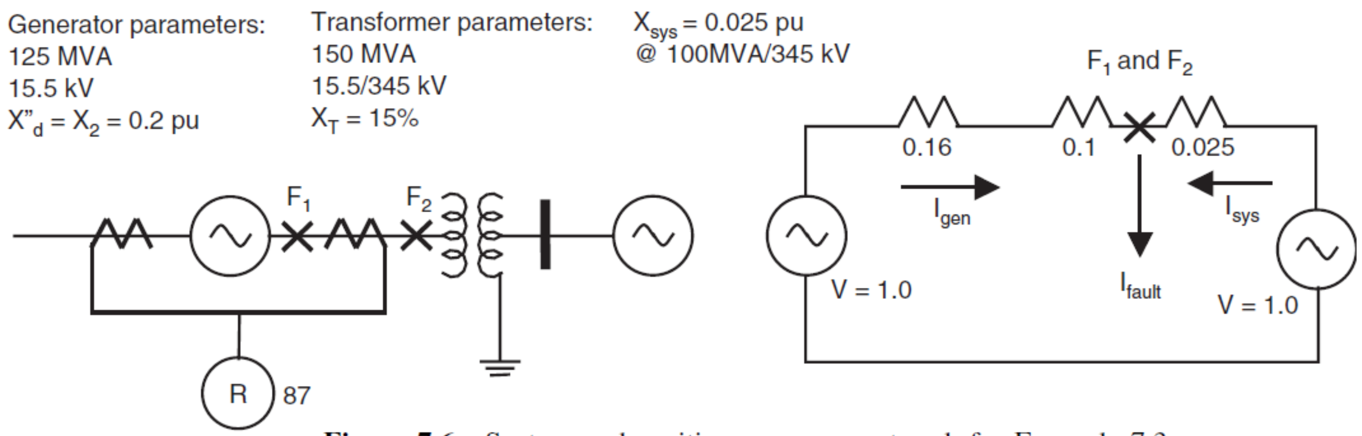


Figure 7.6 System and positive sequence network for Example 7.3

Three-phase faults at F_1 and F_2 are

$$I_{1f} = 1.0/0.07 = 14.29$$

$$I_{base} = 100\,000/(\sqrt{3} \times 15.5) = 3724.9 \text{ A}$$

$$I_f = 14.29 \times 3724.9 = 53228.82 \text{ A}$$

$$I_{gen} = 23\,346/1000 = 23.35 \text{ A, secondary}$$

$$I_{sys} = 29\,883/1000 = 29.89 \text{ A, secondary}$$

$$I''_F = \frac{V_F}{Z_{th}}$$

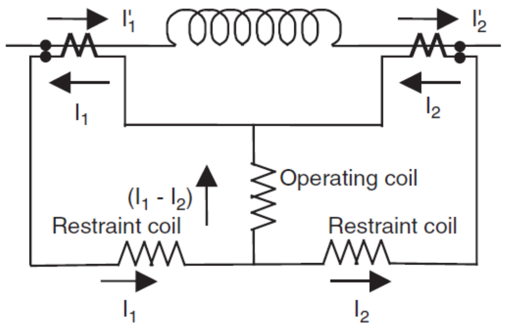


Figure 7.3 Generator differential using percentage differential relay

For a fault at F_2, i.e. outside the generator differential zone, the generator contribution flows through both sets of CTs. If both sets of CTs reproduce the primary current accurately, there will be no current in the operating winding.

For a fault at F_1, i.e. within the differential zone of protection, the generator contribution flows through one set of CTs and the system contribution flows through the other set of CTs. Each restraint winding sees its associated current flowing in opposite directions (which decreases the net restraining torque) and the operating winding sees the sum of the two contributions, i.e. 53.24 A.