Power System Protection

EE454

Lecture file # 8
ODL Week (Dec. 21 – Dec. 24)

- **Note:**

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Session No.	Content of the Lecture presentation (from Ch#8 & 9 of PS Relaying)
Lect. 1	Protection for Multi-winding transformers Non-Electrical Protection of Transformers
Lect. 2	Bus Bar protection


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8.6.1 Multi-winding transformer protection[2]

The CT ratios are chosen so that when any two windings are in service, equal secondary currents are produced. The third winding is assumed to be open-circuited under these conditions. The ratios of all three CTs are chosen in this fashion.

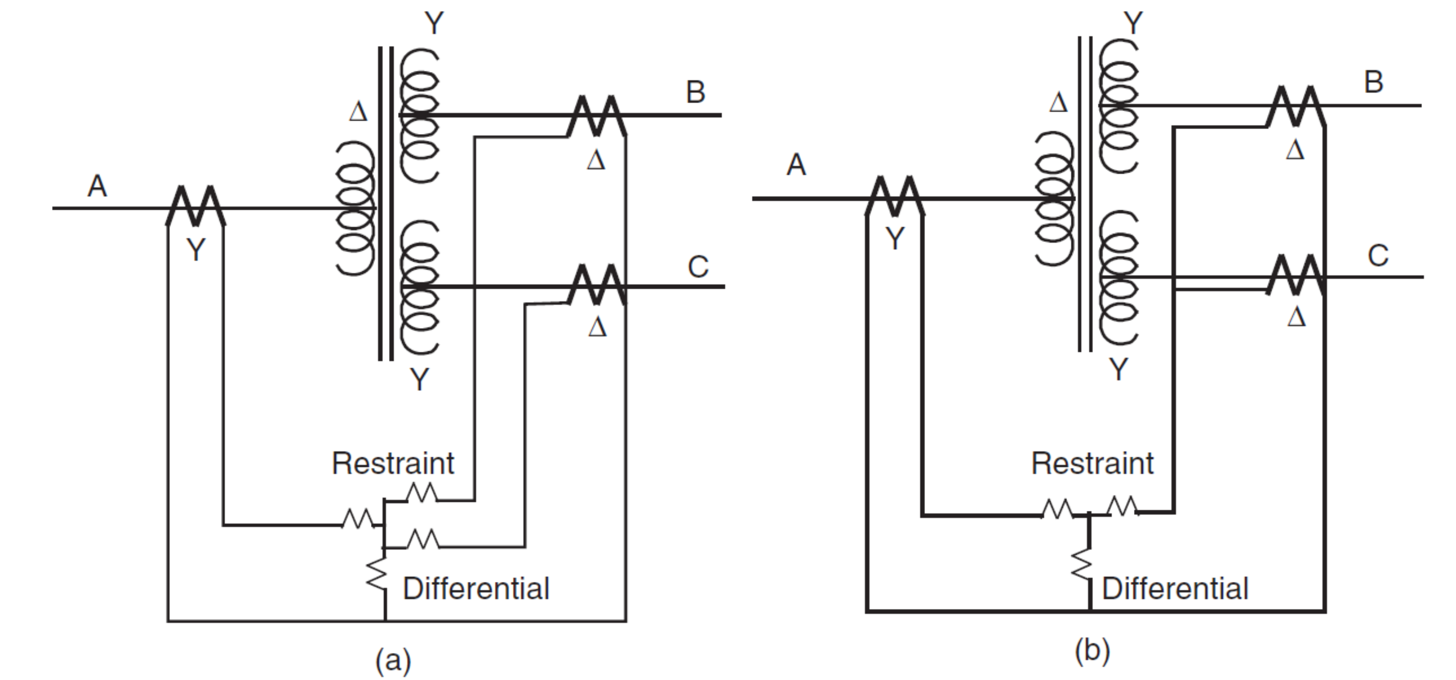


Figure 8.13 Protection of a three-winding transformer with (a) a three-winding relay and (b) a two-winding relay

Option (b) can be used if there is only one source – the CT secondaries of the other two windings can be paralleled and connected to one side of a two winding differential relay.

Example 8.5

Consider the three-phase three-winding transformer shown in Figure 8.13. Let the three windings be rated at: 34.5 kV, delta, 500 MVA; 500 kV, wye, 300 MVA; and 138 kV, wye, 200 MVA. The rated line currents on the delta side have been calculated in Example 8.4 to be 8367.39 A. As before, the CT ratios for the wye-connected CTs on this side are 9000 : 5.

To determine the CT ratios on the 500 kV side, we must assume that the 138 kV side is carrying no load. In this case, the 500 kV side will carry 577.35 A, when the 34.5 kV side is carrying 8367.39 A. (This will be an overload for the 500 kV side, but we are using these figures only to calculate the CT ratios. It is not implied that with the 138 kV side unloaded, the transformer will continue to carry 500 MVA.) As the CTs on the 500 kV side are delta-connected, the CT ratios on this side are 1000 : 5, as in Example 8.4.

The 138 kV side, with the 500 kV side open, and the transformer loaded to 500 MVA (once again, only theoretically, to facilitate calculating the CT ratios), the line currents will be

$$I_{138} = \frac{500 \times 10^6}{\sqrt{3} \times 138 \times 10^3} = 2091.85 \text{ A}$$

Since these CTs are going to be connected in delta, the secondary current should be $5/\sqrt{3} = 2.886$ A. This calls for a CT ratio of 2091.85 : 2.886. This gives the nearest available standard CT ratio of 3600 : 5.

When the transformer is normally loaded, i.e. 500, 300 and 200 MVA in the three windings, the three winding currents will be 8367.39, 346.41 (3/5 of 577.35) and 836.74 (2/5 of 2091.85) amperes, respectively. The corresponding secondary currents produced by the CTs in the relay connection will be

$$\frac{8367.39 \times 5}{9000} = 4.65 \text{ A on the 34.5 kV side}$$

$$\frac{346.41 \times 5}{1000} \times \sqrt{3} = 3.0 \text{ A on the 500 kV side}$$

and

$$\frac{836.74 \times 5}{3600} \times \sqrt{3} = 2.01 \text{ A on the 138 kV side}$$

The differential current will be $4(3.0 + 2.01 - 4.65) = 0.31$ A. With the ample restraint current provided by the three currents in a three-winding differential relay, this relay will not mis-operate for this condition.

Now consider the possibility that a two-winding differential relay is used, with the CT secondaries on the 500 and 138 kV sides being paralleled, as in Figure 8.13(b). Under normal loading conditions determined above, there is no difference in the relay performance. However, consider the case of the 34.5 kV winding being open, and a fault on the 138 kV side being supplied by the system on the 500 kV side of the transformer. Let the fault current on the 500 kV side be 10 000 A and that on the 138 kV side be $10\,000 \times 500/138$ or 36 231 A. The relay currents produced by the two sets of CTs are

$$\frac{10\,000 \times 5}{1000} \times \sqrt{3} = 86.6 \quad \text{from the 500 kV side}$$

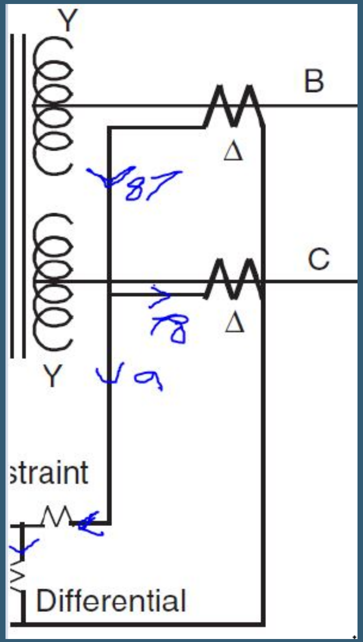
and

$$\frac{36\,231 \times 5}{3600} \times \sqrt{3} = 87.16 \text{ A from the 138 kV side}$$

Assume that the CT on the 500 kV side has a 10 % error, while the CTs on the 138 kV side have negligible error under these conditions. Thus, the current in the differential winding and half the restraint winding of the relay will be

$$(87.16 - 0.9 \times 86.6) = 9.22 \text{ A}.$$

This is equivalent to 200 % of the restraint because only half the restraint winding gets this current, and it being well above the normal pickup setting of 0.25 A for the differential relay, will trip the relay for this condition. It is thus not advisable to use a two-winding differential relay for this case.

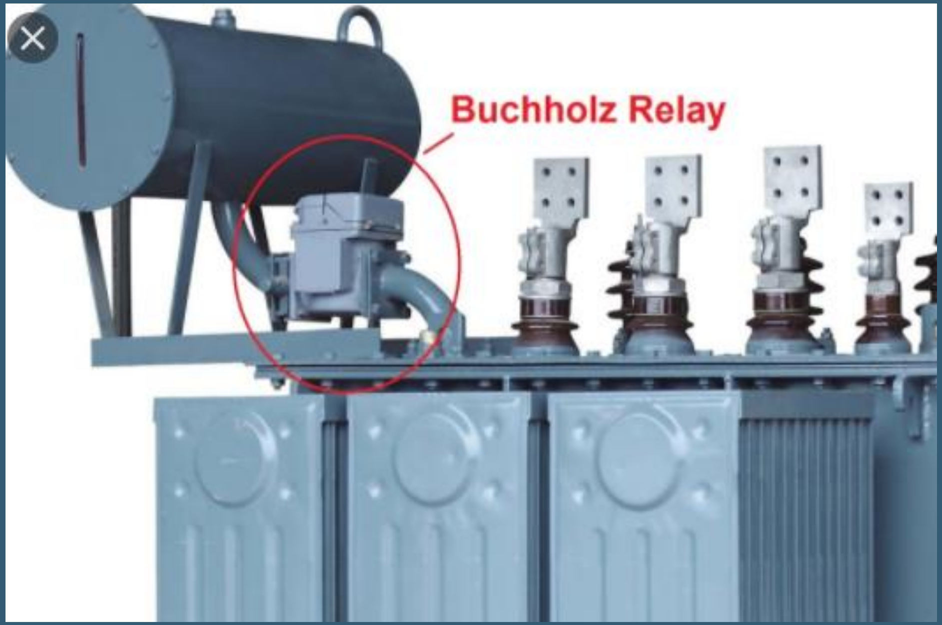


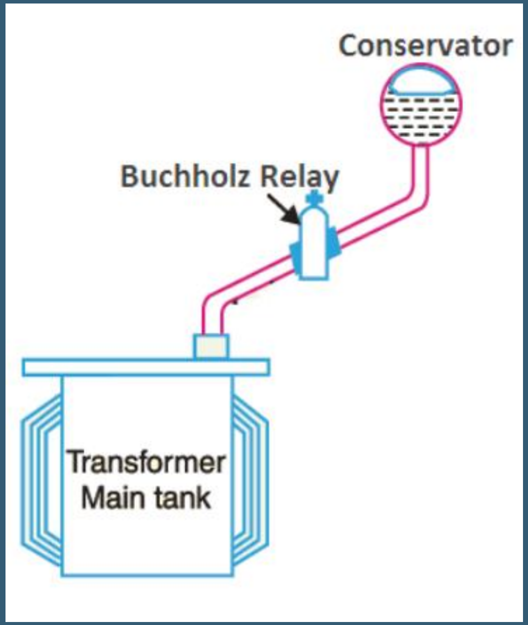
9 A flows in half restraint and full diferential - so 200% fault.

8.8 Nonelectrical protection

8.8.1 Pressure devices

A very sensitive form of transformer protection is provided by relays based upon a mechanical principle of operation. When a fault occurs inside an oil-filled transformer tank, the fault arc produces gases, which create pressure waves inside the oil. In the 'conservator' type of tank construction,[2] which is more common in Europe, the pressure wave created in the oil is detected by a pressure vane in the pipe which connects the transformer tank with the conservator. The movement of the vane is detected by a microswitch, which can be used to sound an alarm, or trip the transformer. This type of a relay is known as a Buchholz relay, named after its inventor.





8.8.2 Temperature devices

There are several temperature-detecting devices used for indication, recording or control, and, on rare occasions, for tripping. Some devices simply measure the oil temperature, usually the top oil. Other devices use a combination of current, by placing a small search coil around a lead, and oil temperature to measure the total effect of load and ambient temperature. The critical temperature is referred to as the 'hot-spot' temperature, and is the highest temperature that will occur somewhere in the winding.

The hot-spot sensors are also commonly used to start and stop cooling fans and pumps. In extreme cases, when it is not possible to remotely remove the load, or send an operator to the station, an extreme high alarm will trip the bank.

9

Bus, reactor and capacitor protection

9.1 Introduction to bus protection

Bus protection systems are more straightforward than transformer protection systems because the variables are reduced. There is no ratio or phase angle change or appreciable inrush.

historically bus protection has been the most difficult protection to implement because of the severity of an incorrect operation on the integrity of the system. A bus is one of the most critical system elements. It is the connecting point of a variety of elements and a number of transmission lines, and any incorrect operation would cause the loss of all of these elements. This would have the same disastrous effect as a large number of simultaneous faults.

The major problem with bus protection has been unequal core saturation of the current transformers (CTs). This unequal core saturation is due to the possible large variation of current magnitude and residual flux in the individual transformers used in the system. In particular, for a close-in external fault, one CT will receive the total contribution from the bus while the other CTs will only see the contribution of the individual lines.

Protection of substation buses is almost universally accomplished by differential relaying. This method makes use of Kirchhoff's law that all currents entering or leaving a point (the substation bus) must sum vectorially to zero. In practice, this type of protection is accomplished by balancing the CT secondary current of all of the circuits connected to the bus and then bridging this balanced circuit with a relay operating coil.

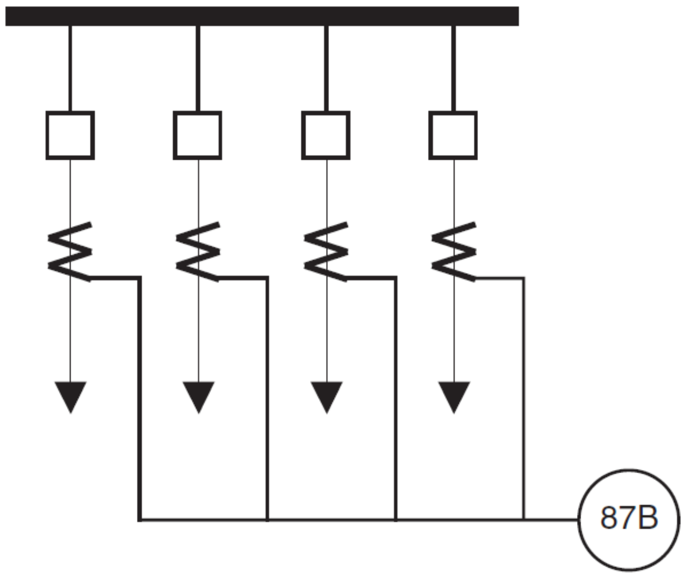


Figure 9.1 Differential with overcurrent relays

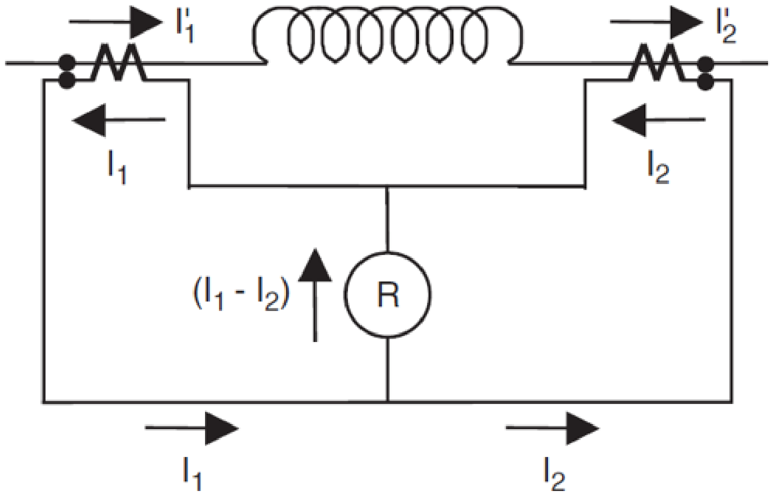


Figure 7.1 Generator differential connection with overcurrent relay

9.3 Percentage differential relays

To avoid the loss of protection that results from setting the overcurrent relay above any error current, as discussed in Chapters 7 and 8, it is common to use a percentage differential relay. These relays have restraint and operating circuits as shown in Figure 9.2. Only one operating coil per phase is required, but one restraint winding for each phase of each circuit is necessary. This is conceptually similar to the transformer differential discussion in Chapter 8. Normally, one restraint winding is connected to each circuit that is a major source of fault current. Feeders and circuits with low fault-current contribution may be paralleled on a single restraint winding.

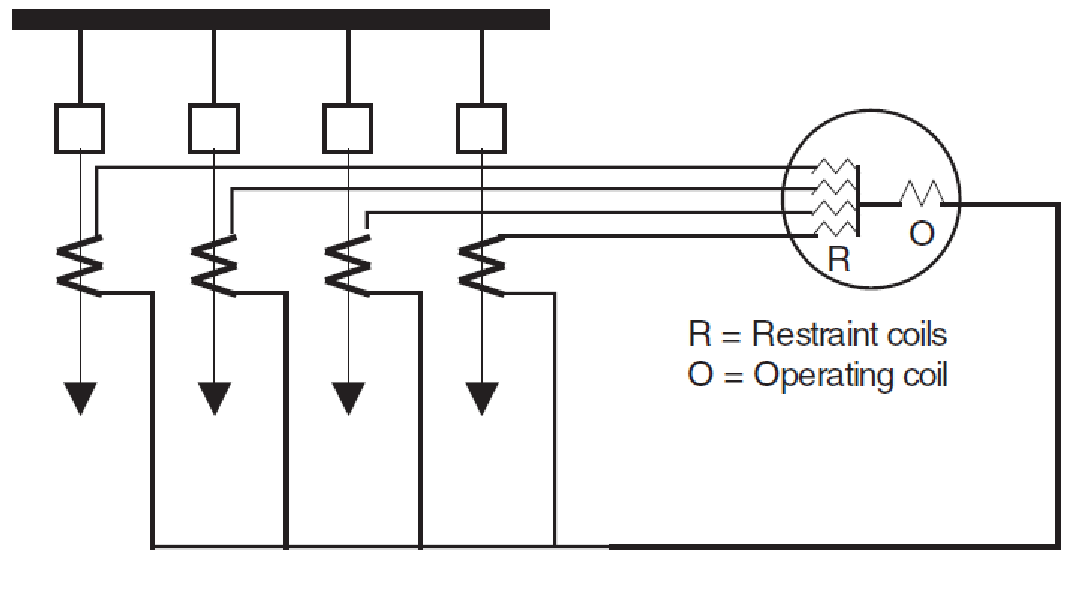
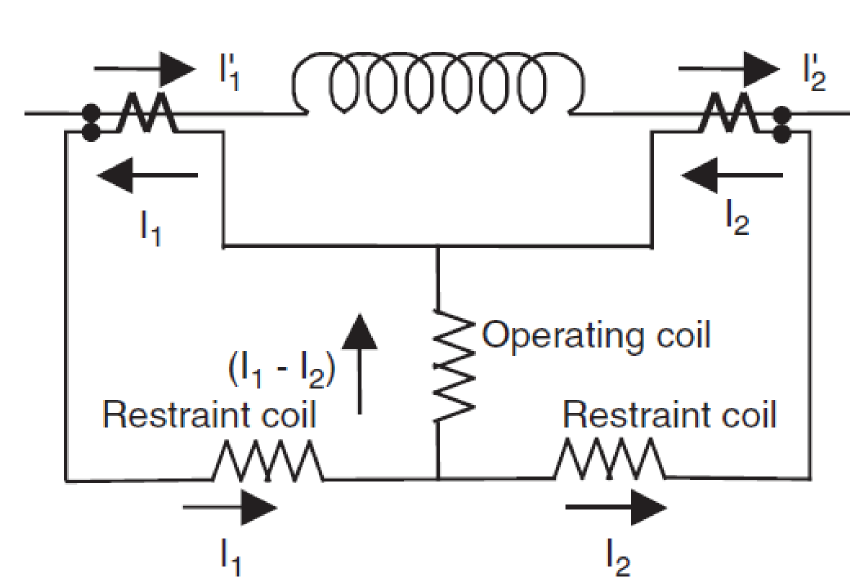


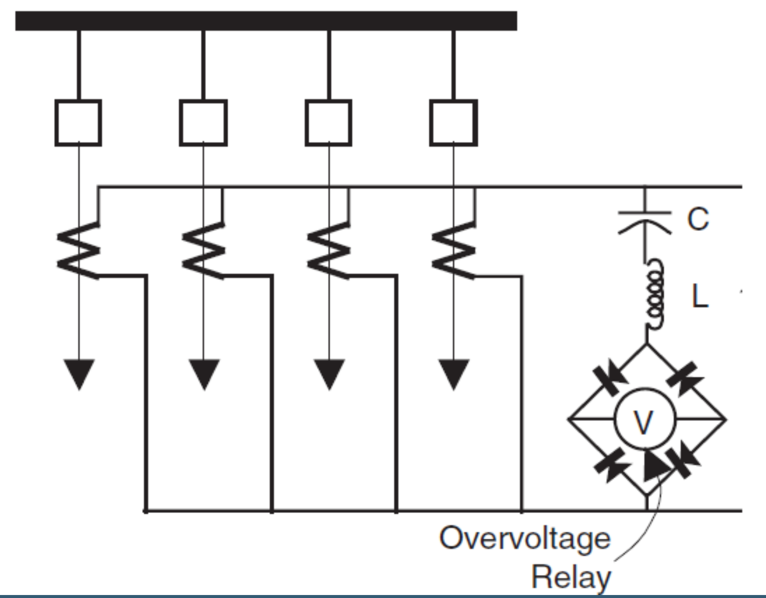
Figure 9.2 Percentage differential relay



9.4 High-impedance voltage relays

Even with the use of percentage differential relays, the problem of the completely saturated CT for a close-in external fault still exists. To overcome this problem, the most commonly used bus differential relay, particularly on extra high voltage (EHV) buses, is the high-impedance voltage differential relay.

This relay design circumvents the effects of CT saturation during external faults by assuming complete saturation for the worst external fault and calculating the error voltage across the operating coil. The relay discriminates between internal and external faults by the relative magnitudes of the voltage across the differential junction points.[1]



The L–C circuit in series with the overvoltage relay is tuned to 60 Hz to prevent the overvoltage relay from mis-operating on DC offset or harmonics.

Example 9.1

Referring to the simplified circuit of Figure 9.4, a typical setting calculation is as follows.

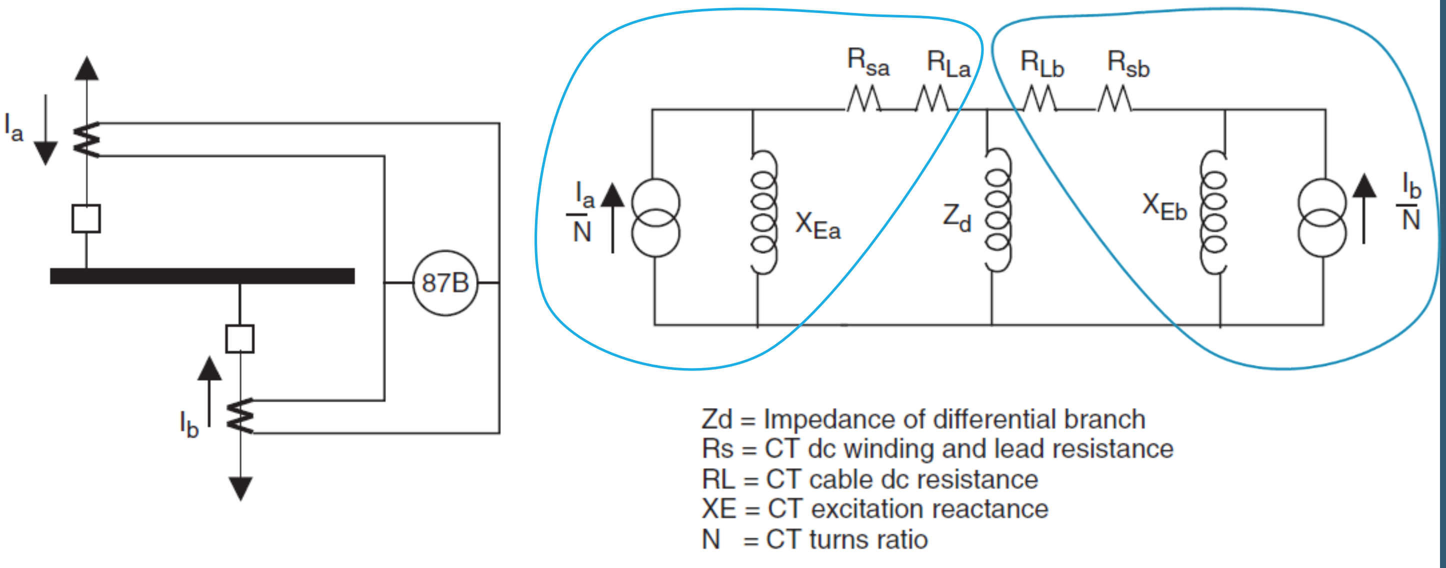


Figure 9.4 Equivalent circuit for Example 9.1

Upon the initial occurrence of an internal fault, X_{ea}, X_{eb} and Z_d can be assumed to be very large. Currents I_a/N and I_b/N will tend to be forced through the large impedances in such a direction as to cause a high voltage to be developed across the differential branch, hence operating the relay. If an external fault occurs on line B, assuming no saturation, I_b/N will equal $-I_a/N$ and circulate around the outer loop, developing no net voltage across the relay. For the same fault, assuming complete CT saturation, X_{eb} is approximately zero, producing a net error voltage across the relay equal to $(R_{lb} + R_{sb})I_a/N$. This voltage, which is the basis for setting the relay, is generally much lower than that generated by the minimum internal fault. Note that smaller CT winding and lead resistances will allow lower and more sensitive settings. All the current transformers should have the same ratio and should have the lowest effective secondary leakage. This is obtained with distributed windings on toroidal cores connected to the maximum tap. The use of auxiliary CTs is not recommended.

Example 9.2

Given the equivalent circuits shown in Figure 9.5 for an external and internal fault, the voltage across 87B for the external fault is $I_{total} \times R_{lead}$ or $60 \times 2 = 120$V. Set the relay at twice this value

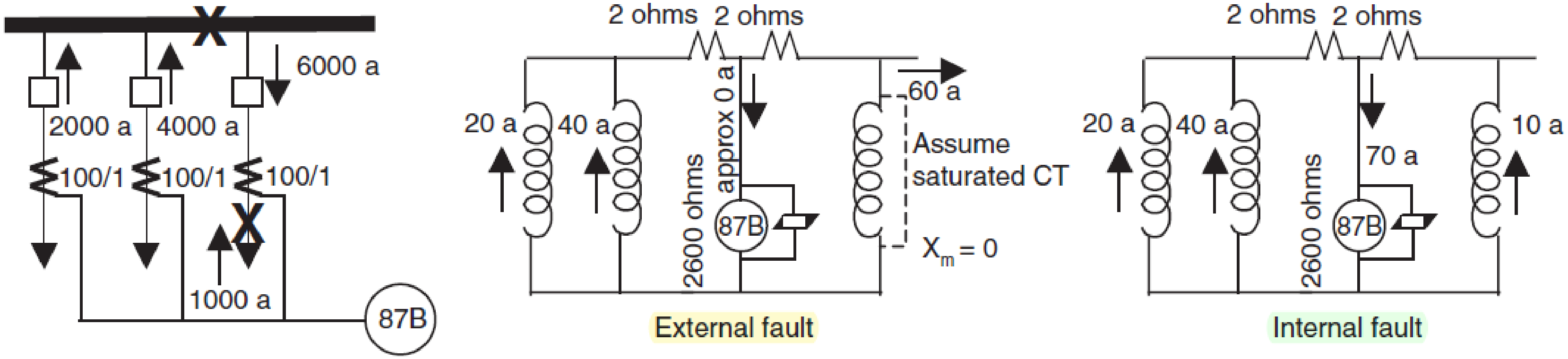


Figure 9.5 Equivalent circuits for Example 9.2

or 240 V. For an internal fault, the total current is 70 A times the relay resistance of 2600 Ω, or 182 kV. Obviously, such a high voltage cannot be developed without serious insulation damage. The variable resistor is used to limit the voltage by reducing the resistance as the voltage increases.