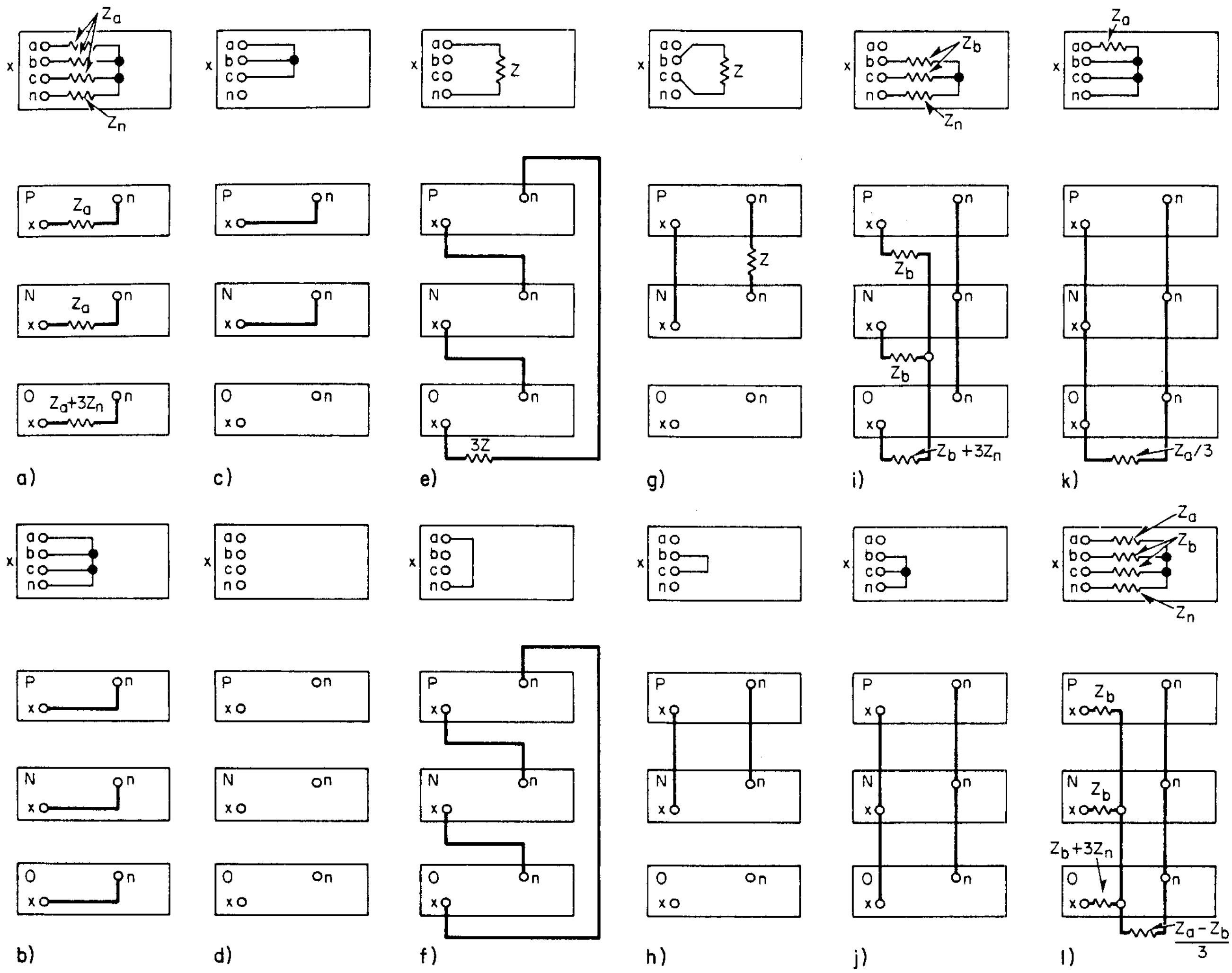
(W) Applied Protective Relaying



Note:

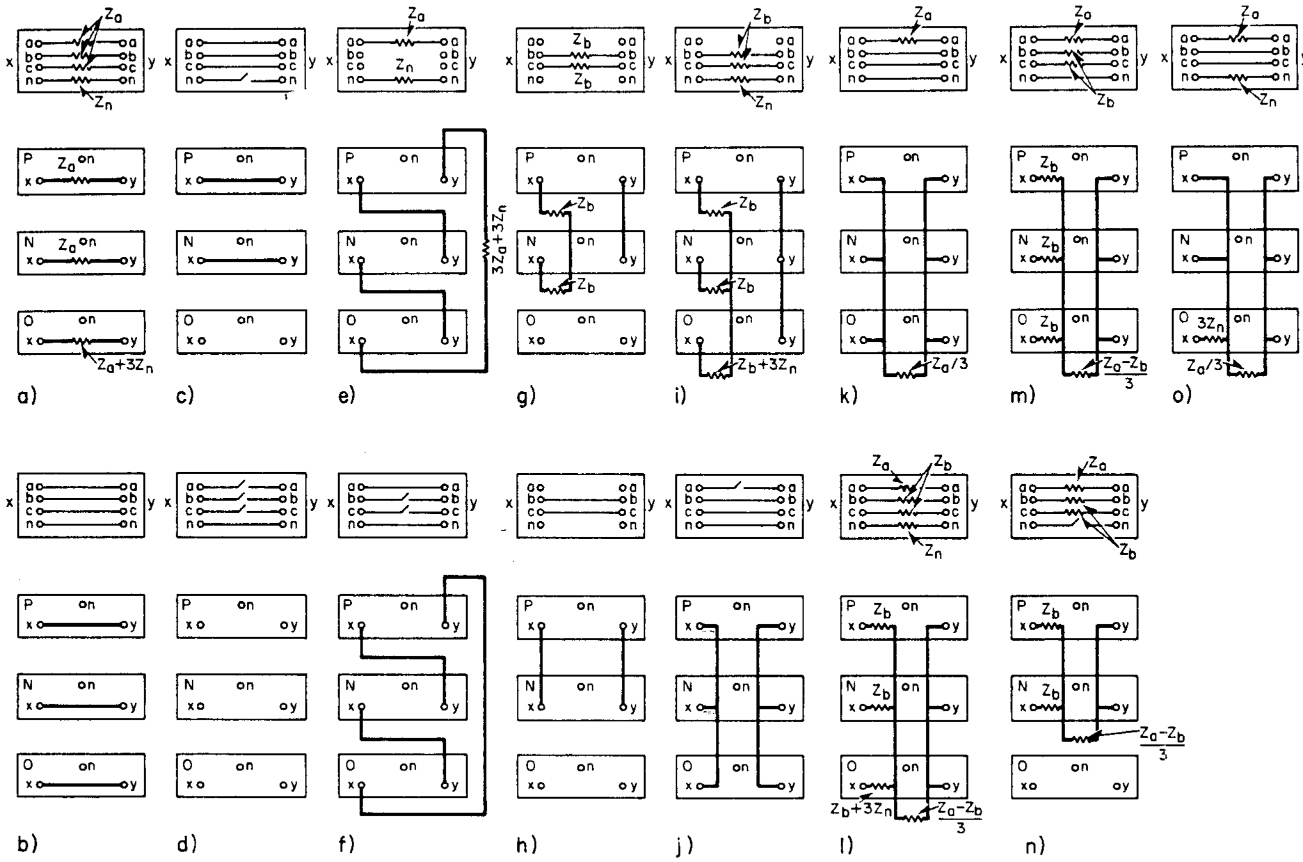
a) Balanced load or three-line-to-ground fault with impedances.
b) A three-line-to-ground fault.
c) A three-phase fault.
d) A shunt circuit open.
e) A line-to-ground fault through an impedance.
f) A line-to-ground fault.
g) A line-to-line fault through impedance.
h) A line-to-line fault.
i) A two-line-to-ground fault with impedance.
j) A two-line-to-ground fault.
k) A three-line-to-ground fault with impedance in phase a.
l) Unbalanced load or three-line-to-ground fault with impedance.

Figure 2-31: Sequence Network Interconnections for Shunt Balanced and Unbalanced Conditions.

In Figure 2-31, the entire symmetrical power system up to a point, x, of the shunt connection is represented by a rectangular box. Inside the topmost box for each shunt condition is a four-line representation of the shunt to be connected to the system at point x. The three lower boxes for each shunt condition are the positive, negative, and zero sequence representation of the shunt.

The sequence connections for the series unbalances, such as open phases and unbalance series impedances, are shown in Figure 2-32. As before, these diagrams are taken from E. L. Harder's study. Here again, the diagrams inside the topmost box for each series condition represent the area under study, from point x on the diagrams left to point y on the right. The power system represented by the box is open between x and y to insert the circuits shown inside the box. Points x and y can be any distance apart, as long as there is no tap or other system connection between them. The positive, negative, and zero sequence representations of the top box are shown in the three boxes below it.

The diagrams shown in Figures 2-31 and 2-32, particularly those of Figure 2-32, are useful both for visualizing and calculating the conditions for open phases and unbalances.



Note:

a) Equal impedances in three phases.
b) Normal conditions.
c) Neutral open.
d) Any three or four phases open.
e) Phases b and c open, impedances in phases a and neutral.
f) Phases b and c open.
g) Phases a and neutral open, impedance in b and c.
h) Phases a and neutral open.
i) Phase a open, impedances in b, c, and neutral.
j) Phase a open.
k) Impedance in phase a.
l) Equal impedances in b and c phases, and neutral.
m) Equal impedances in b and c phases.
n) Equal impedances in b and c phases, neutral open.
o) Impedances in phase a and neutral.

Figure 2-32: Sequence Network Interconnections for Series Balanced and Unbalanced Conditions.

Simultaneous faults require two sets of interconnections from either Figures 2-31 or 2-32—or both. As shown in Figure 2-33, ideal or perfect transformers can be used to isolate the two restrictions. Perfect transformers are 100 percent efficient and have ratios of 1:1, 1:a, 1:a^2, and so on.

It is sometimes necessary to use two transformers as shown in Figure 2-33 (f). In this case the first transformer, ratios $1:\epsilon^{-j30^o}$, $1:\epsilon^{j30^o}$ and 1:1 represent the star-delta transformer and the second transformer with ratios 1:a^2, 1:a, 1:1 represents the b-to-neutral fault. These can be replaced by an equivalent transformer with ratios $1:\epsilon^{-j150^o}$, $1:\epsilon^{j150^o}$ and 1:1.

Figure 2-33a, for example, represents an open phase-a conductor with a simultaneous fault to ground on the x side. The sequence networks are connected for the open conductor according to Figure 2-32j, with three 1:1 perfect transformers to provide the restrictions required by Figure 2-31f. The manual calculations required, which involve the solution of simultaneous equations, are quite tedious.

V.G. Sequence Network Reduction

When manual calculations are performed, the complete system networks (Figures 2-23, 2-24, and 2-25) are reduced to the single impedance values of Figures 2-27 through 2-30.

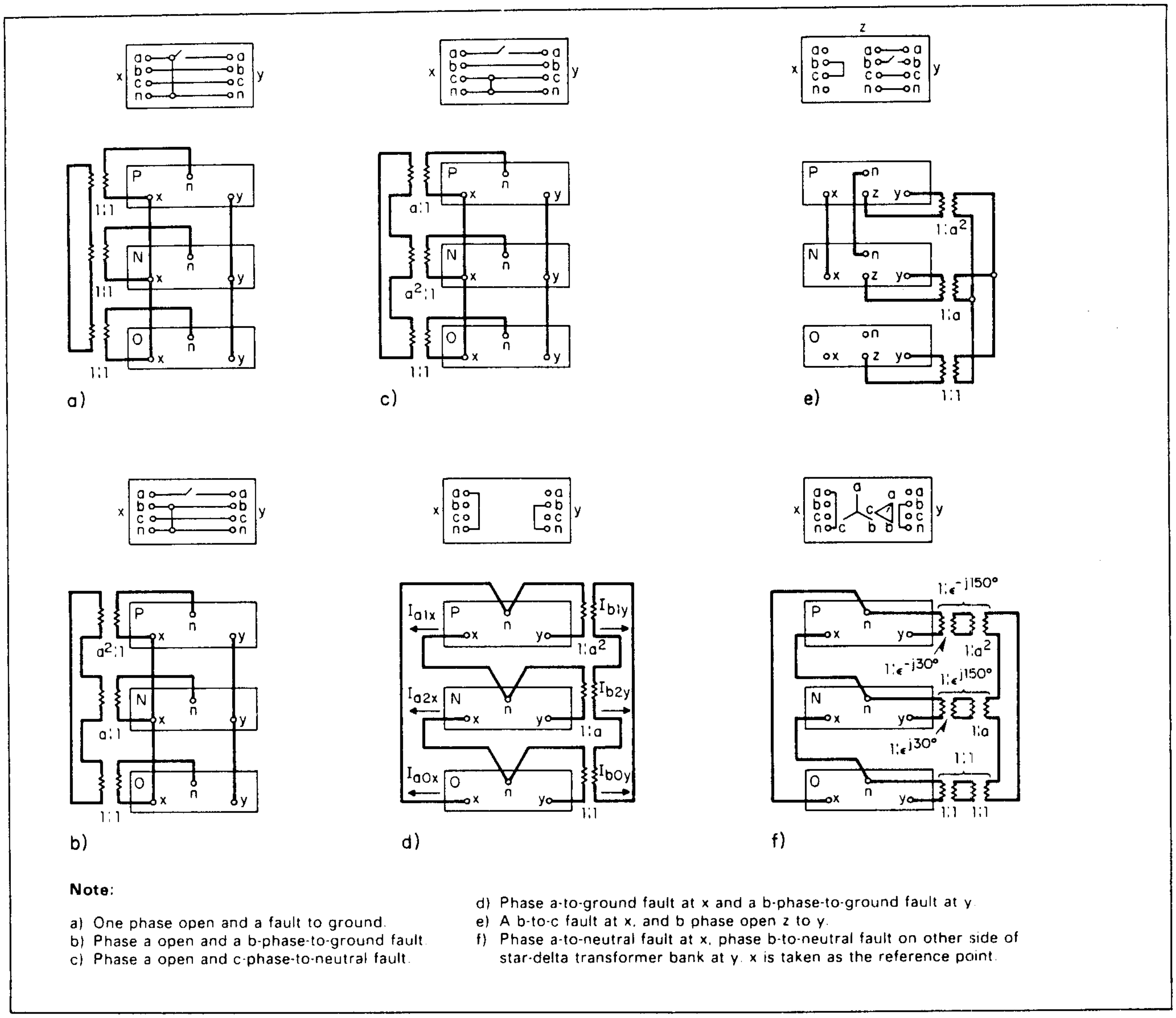


Figure 2-33: Representations for Simultaneous Unbalances.

To simplify this reduction, with negligible effect on the values, the following basic assumptions are made:

- All generated voltages are equal and in phase
- All resistance is neglected, or the reactance of machines and transformers is added directly with line impedances
- All shunt reactances are neglected, including loads, charging, and magnetizing reactances
- All mutual reactances are neglected, except on parallel lines.

Using these assumptions, the positive sequence network can be drawn with a single-source voltage, V_{an}, connected to the generator impedances by a bus.

If voltages are different, the Thevenin theorem and superposition must be used to reduce the network and calculate faults. Note that, for the series unbalances of Figure 2-32, a difference in voltage—either magnitude, phase angle, or both—is required for current to flow. No current can exist if the voltages across an open phase are equal and in phase.

The single-sequence impedances, Z_1, Z_2, and Z_0, of Figures 2-27 through 2-30, will be different for each fault lo-