Short Circuit Currents

Abdul Basit

Power System Protection

Short Circuit Currents

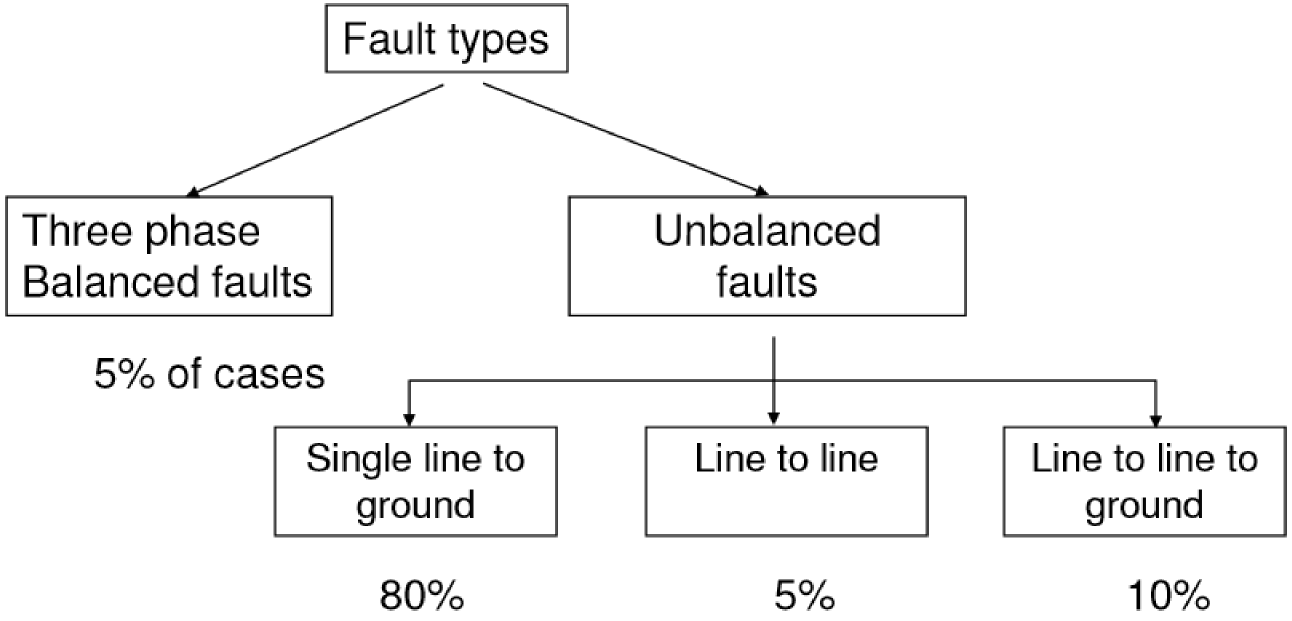
- Current flowing through an element of a power system is a parameter that can be used to detect faults, given the large increase in current flow when a short-circuit occurs.
- Short-circuit calculations are used for protection, the selection of conductor sizes and for the specifications of equipment such as power circuit breakers.
- Electrical faults are characterized by a variation in the magnitude of the short-circuit current due to the effect of the equivalent system impedance at the fault point that produces a decaying DC component, and the performance of the rotating machinery that results in a decaying AC component.

Short-circuit currents

- The resulting short-circuit current is determined by the internal voltages of the synchronous machines and the system impedances between the machines voltages and the fault.
- Short-circuit currents may be several orders of magnitude larger than normal operating currents
- If allowed to persist
  - thermal damage to equipment
  - mechanical damage due to high magnetic forces during faults: windings & bus-bars
- necessary to remove the faulted sections of a power system from service as soon as possible

Fault (short-circuit) studies

- Determine:
  - bus voltages
  - line currents
    … during various types of faults



Fault types

Three phase Balanced faults

5% of cases

Unbalanced faults

Single line to ground

80%

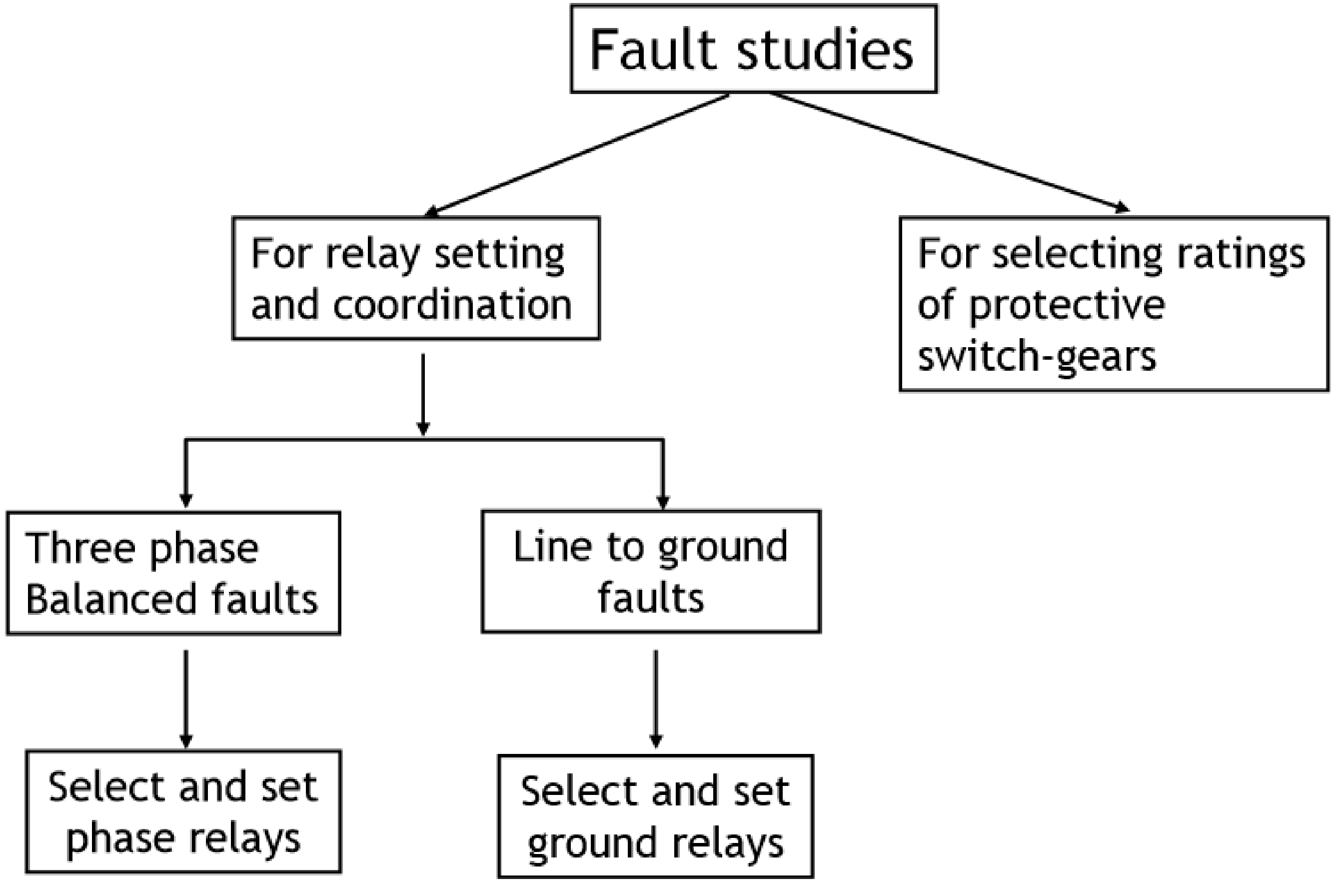
Line to line

5%

Line to line to ground

10%

Why fault studies?



Fault studies

For relay setting and coordination

For selecting ratings of protective switch-gears

Three phase Balanced faults

Line to ground faults

Select and set phase relays

Select and set ground relays

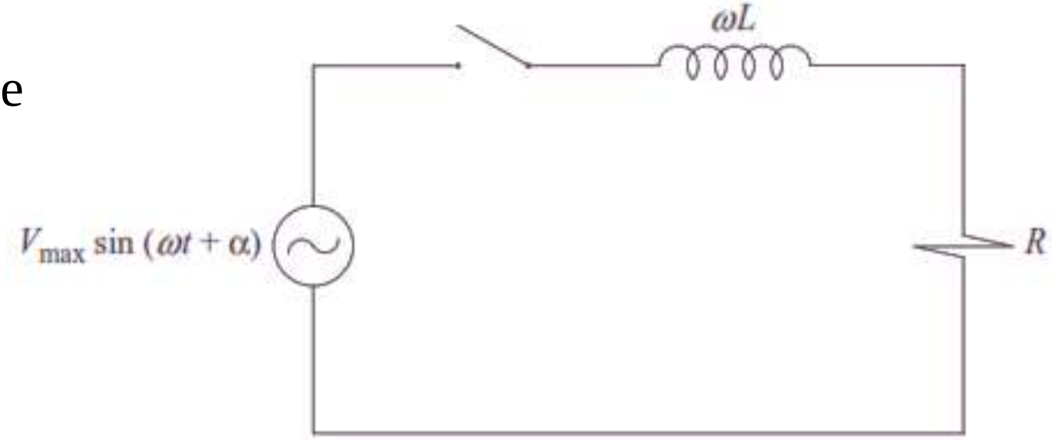
System impedance effect

- During Faults, network impedance resists the change in system current resulting in decaying DC component
    - Rate of decay depends on the instantaneous value of the voltage when the fault occurs and the power factor of the system at the fault point
    - Differential equations are used to calculate fault currents that vary with time
- Transient nature of current is equivalently modelled as simplified RL circuit
    - Simplification is important as all system equipment must be modelled in some way in order to quantify the transient values that can occur during the fault condition

System impedance effect

Mathematical expression that defines the behavior of the current is

$$e(t) = L\frac{di}{dt} + Ri(t)$$



$$i(t) = i_h(t) + i_p(t)$$

Transient period

Steady State period

Varies Sinusoidal

Decrease exponentially

Complete Solution

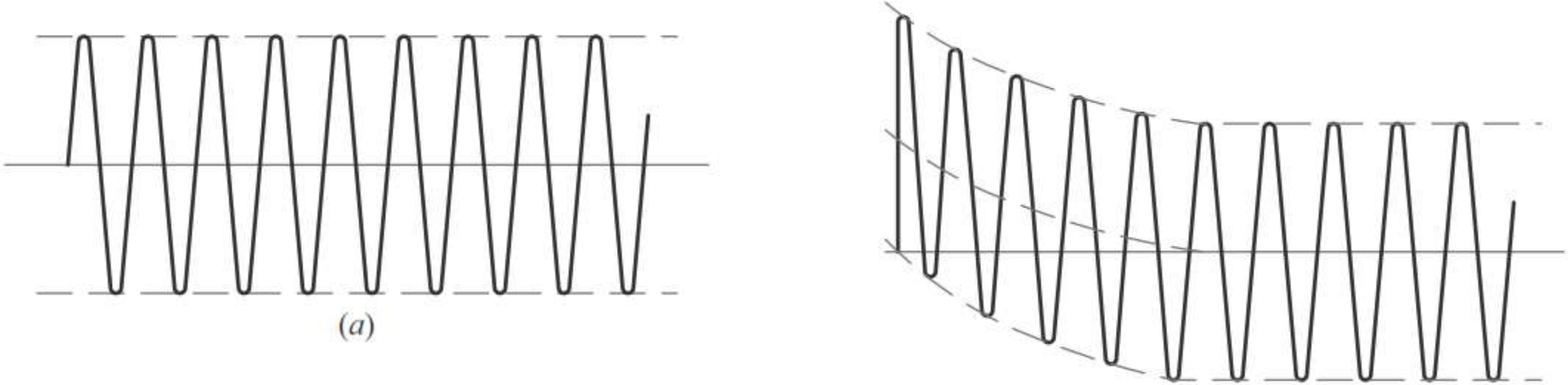
$$i(t) = \frac{V_{\max}}{Z}\left[\sin(\omega t + \alpha - \phi) - \sin(\alpha - \phi)\,e^{-(R/L)t}\right]$$

where α is the closing angle that defines the point on the source sinusoidal voltage

$$Z = \sqrt{R^2 + \omega^2 L^2} \qquad \phi = \tan^{-1}\frac{\omega L}{R}$$

System impedance effect

- In previous equation, first term corresponds to the AC component, whereas the second term can be recognized as the DC component of the current having an initial maximum value when $\alpha - \phi = \pm\pi/2,$, and zero value when $\alpha = \phi$


(a)

(b)

Variation of fault current with time: (a) $\propto -\phi = 0$ *and (b)* $\propto -\phi = -\pi/2$

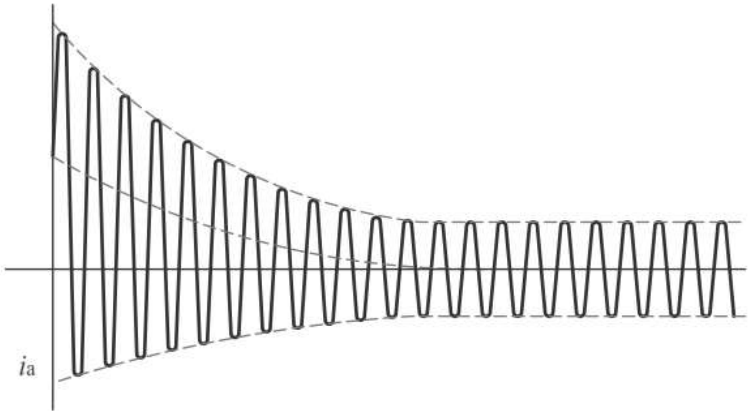
System impedance effect

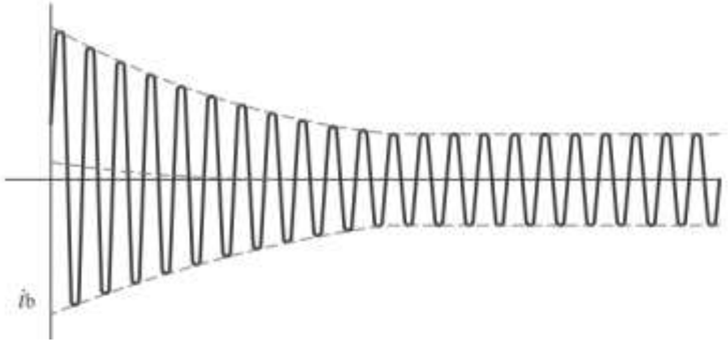
- Total asymmetrical current, including the AC and DC components, with acceptable accuracy can be used by assuming that these components are in quadrature with the following expression:

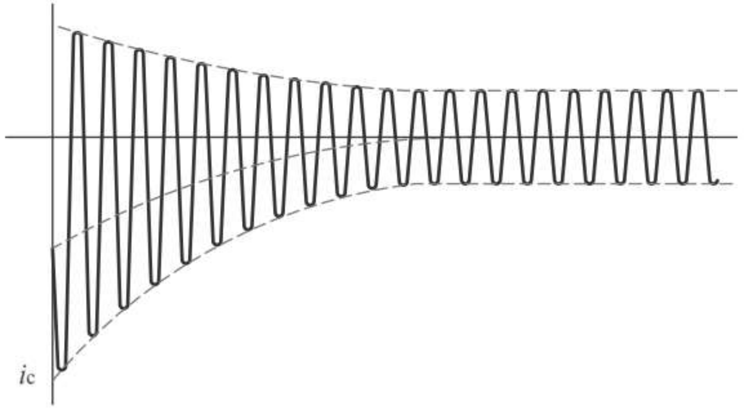
$$I_{\text{rms.asym.}} = \sqrt{I_{\text{rms}}^2 + I_{\text{DC}}^2}$$

Effect of rotating machinery

- Fault at the terminals of rotating machinery produces a decaying AC current, similar in pattern as RL circuit
- Decaying pattern is due to the fact that the magnetic flux in the windings of rotating machinery cannot change instantaneously.
  - gradual decrease in the magnetic flux causes reduction in current from its value

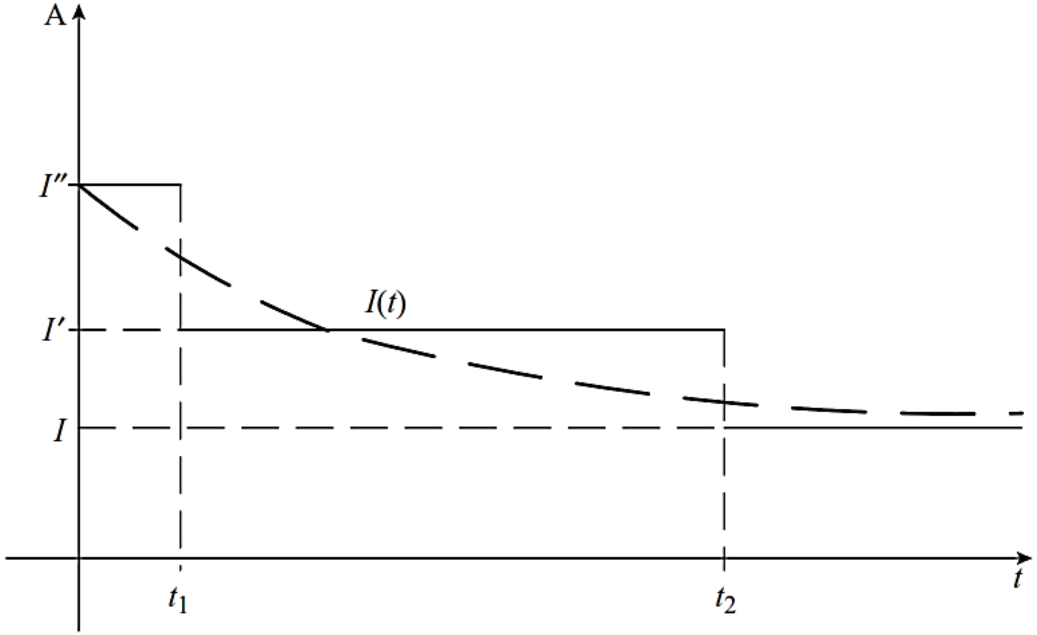


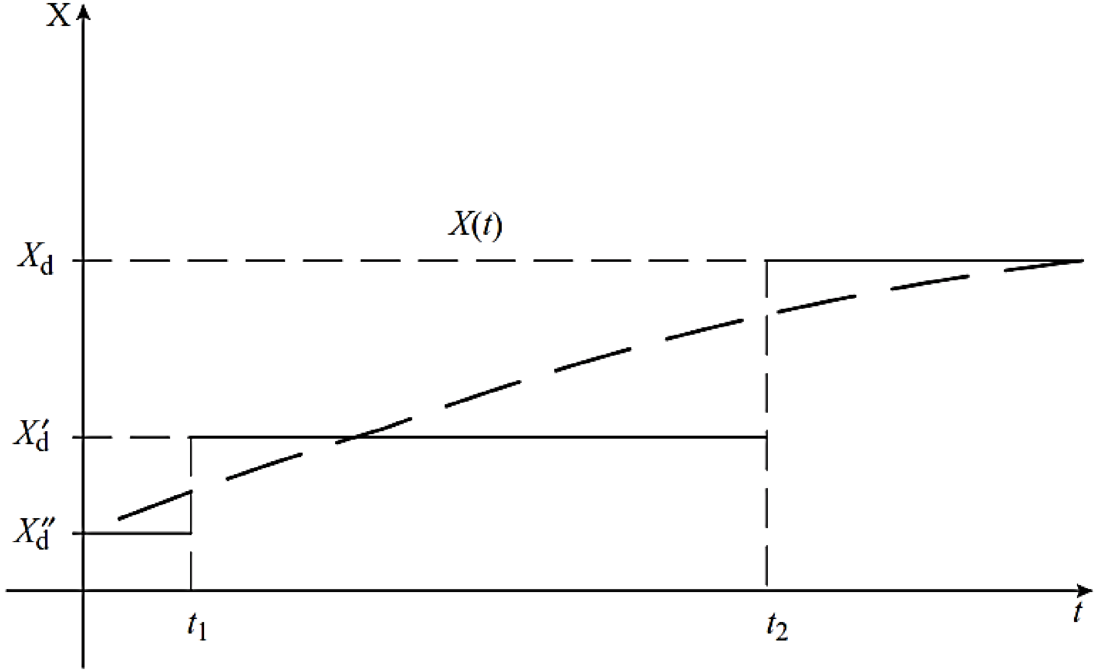




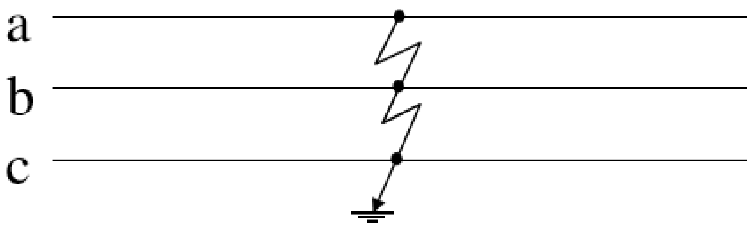
Effect of rotating machinery

- Variation of current with time, $I(t)$, *comes close to the three discrete levels of current,* I'', I' *and* I *– the* subtransient, transient and steady-state currents, respectively corresponds to the values of direct axis reactance are denoted by X'', X' *and* X



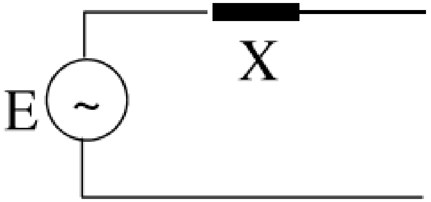


Balanced three-phase faults



- Occurs infrequently
- But the most severe type
- Network is balanced → solve using per phase basis

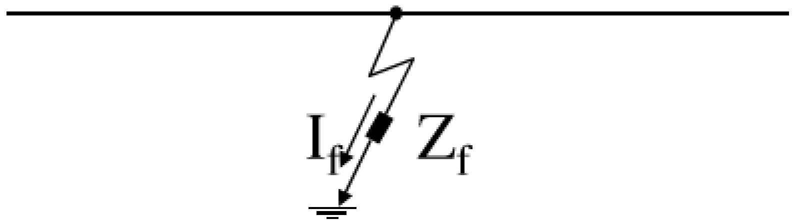
Synchronous generator reactance



- X = X”d → Sub-transient reactance, for the first few cycles of the short-circuit current
- X = X’d → Transient reactance, for the next 30 cycles of the short-circuit current
- X = Xd → synchronous reactance, thereafter

Fault impedance

- Fault often involves impedance of itself (eg. arc resistance), Z_f
- $Z_f = 0$ → bolted fault of solid fault

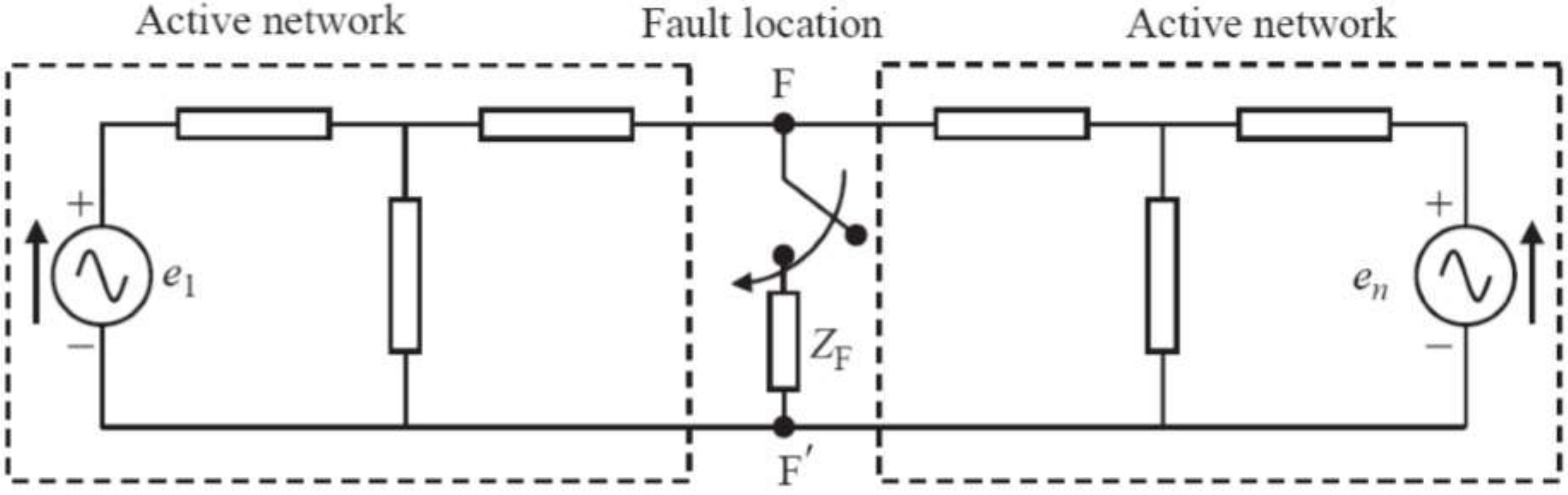


- How to calculate current I_f ?
  → Thevenin's theorem

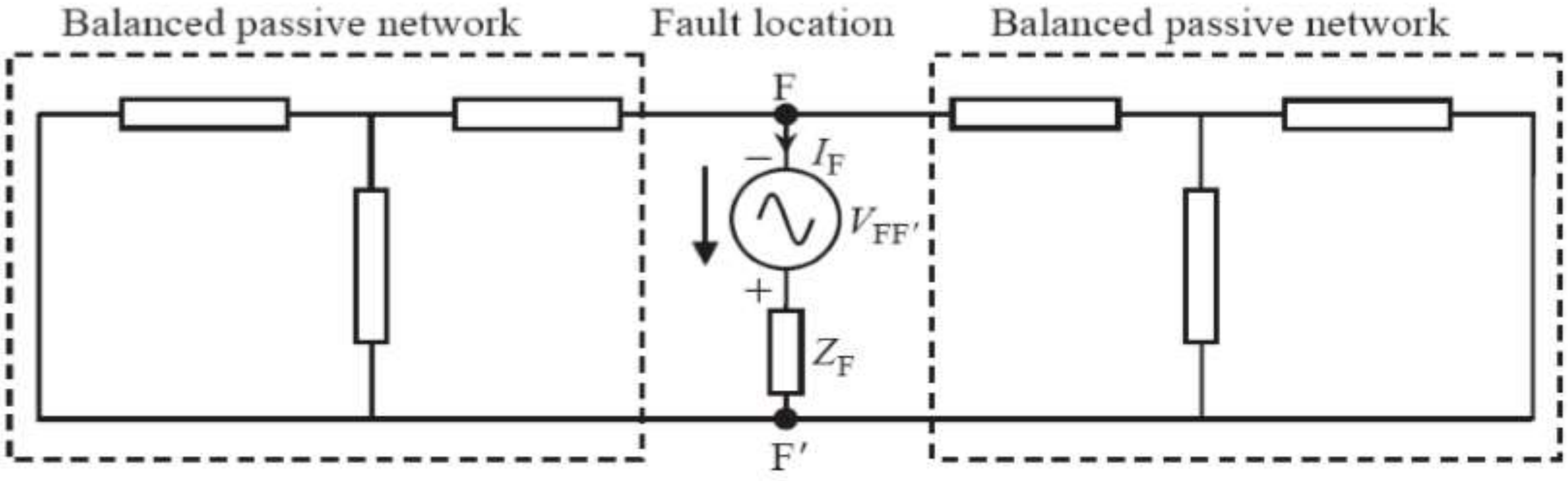
Thevenin theorem

“Changes in network voltages caused by an added branch (fault impedance) at a node is equivalent to those caused by the added voltage source Vth= V(0) (pre-fault voltage) at that node with all other voltage sources shorted.”

Thevenin and superposition theorem



Thevenin and superposition theorem



Assumptions for calculations

- Transformers are represented by their leakage reactance. Winding resistances, shunt admittance and Δ-Y phase shifts are neglected.
- Transmission lines are represented by their equivalent series reactance. Series resistances and shunt admittances are neglected.
- Synchronous machines are represented by a constant voltage source behind the (sub) transient reactance (depending on types of fault analysis). Armature resistance, saturation are neglected.
- All non-rotating impedance loads are neglected.
- Induction motors are either neglected (<50hp), or represented in the same manner as synchronous machines.

Steps in short-circuit calculation

1. The pre-fault bus voltages are obtained from the results of a load flow analysis.
2. Loads are converted to constant impedances to ground using the bus voltages.
3. The faulted network is reduced into a Thevenin equivalent circuit viewed from the faulted bus. Applying Thevenin's theorem, changes in bus voltages are obtained.
4. Bus voltages during the fault are obtained by superposition of the pre-fault bus voltages and the changes in the bus voltages computed in the previous step.
5. The currents during the fault may now be obtained in all branches of the faulted system.