Stator DC Current Component

- **The expression for the stator current for the simplified machine model does not include the effects of the decaying exponential unidirectional current**
- **The dc component is a function of the machine's rotor position, which is indicated by δ when the short-circuit is applied at t = 0**
  - The time constant associated with the decay of the dc component is known as the armature short circuit time constant, τ_a

$$\tau_a = \frac{X''_d + X''_q}{2\,R_a}$$

Typical time constants range around 0.05 to 0.17 seconds

Stator DC Current Component

- A generator has three windings separated by 120º; each phase will have a different dc component depending on the point of the voltage cycle at which the short circuit occurs

$$I_{dc-a} = \sqrt{2}\,\frac{E_0}{X''_d}\left(\sin\delta\right)e^{-t/\tau_a}$$

- Combining the ac and dc components using superpositioning results in

$$i_{ac}(t) = \sqrt{2}\,E_0\left[\left(\frac{1}{X''_d}-\frac{1}{X'_d}\right)e^{-t/\tau''_d}+\left(\frac{1}{X'_d}-\frac{1}{X_d}\right)e^{-t/\tau'_d}+\frac{1}{X_d}\right]\sin\left(\omega t+\delta\right)$$

$$+\sqrt{2}\,\frac{E_0}{X''_d}\left(\sin\delta\right)e^{-t/\tau_a}$$

Determining the Transient Constants

- **The generator transient constants can be estimated by analyzing the current waveforms of a fault applied at the generator terminals**
  - The current waveform must not have any dc components - i.e. the fault was applied at a voltage peak
- **Data preparation**
  - No-load / open circuit terminal voltage of the generator
  - The current waveform is divided into three periods
    - the subtransient period - first few cycles where the current decreases rapidly
    - the transient period - 1 to 2 cycles where the current has a moderate decay
    - the steady-state period

Determining the Transient Constants

- **Method**
  - First, determine the synchronous reactance, using the current value where the waveform envelope becomes constant

$$I_d = \frac{1}{\sqrt{2}} I_{d\,(\max)} \qquad X_d = \frac{E_0}{I_d}$$

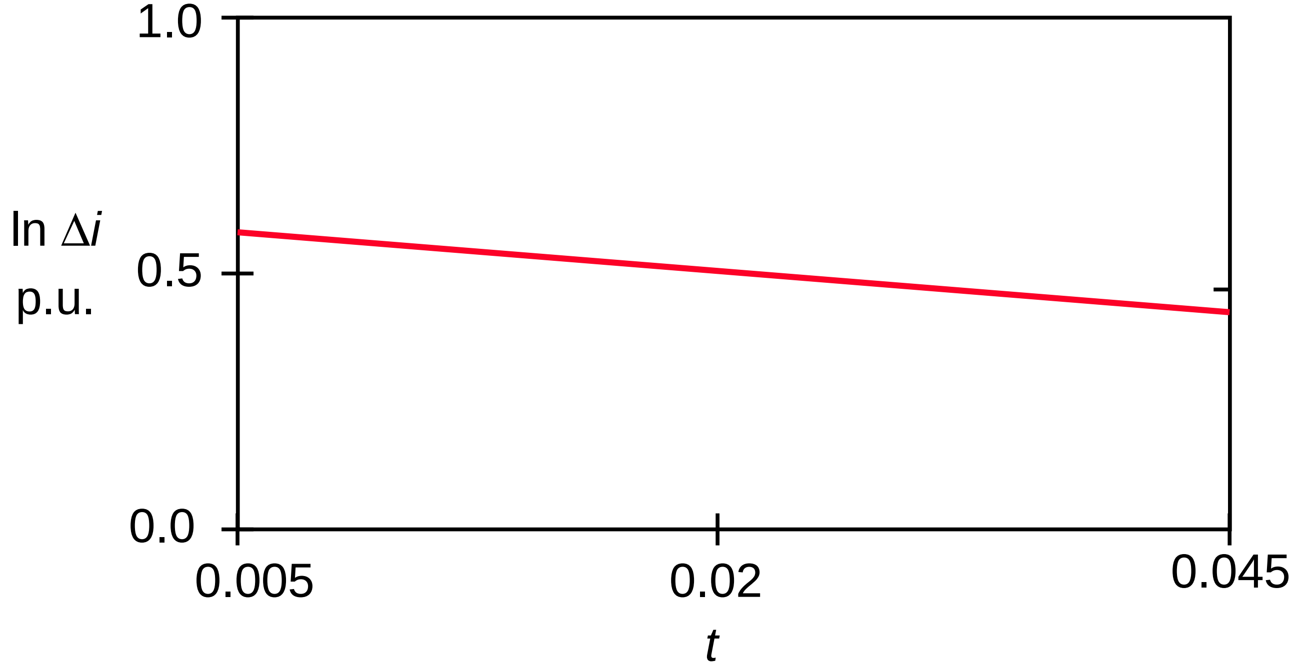
  - Second, using the part of the envelope between the subtransient time period and the steady state time period
    - the steady state current is subtracted from the transient current
    - the logarithmic curve of the envelope is plotted with respect to linear time as a straight line
    - the y-intercept and the slope are obtained from the graph

Determining the Transient Constants

$$\Delta i' = \left(I_d' - I_d\right) e^{-t/\tau_d'}$$

$$\ln \Delta i' = \ln\left(I_d' - I_d\right) - t/\tau_d' = c' - m' t$$

$$I_d' = e^{c'} + I_d \qquad X_d' = \frac{E_0}{I_d'} \qquad \tau_d' = \frac{1}{m'}$$



Determining the Transient Constants

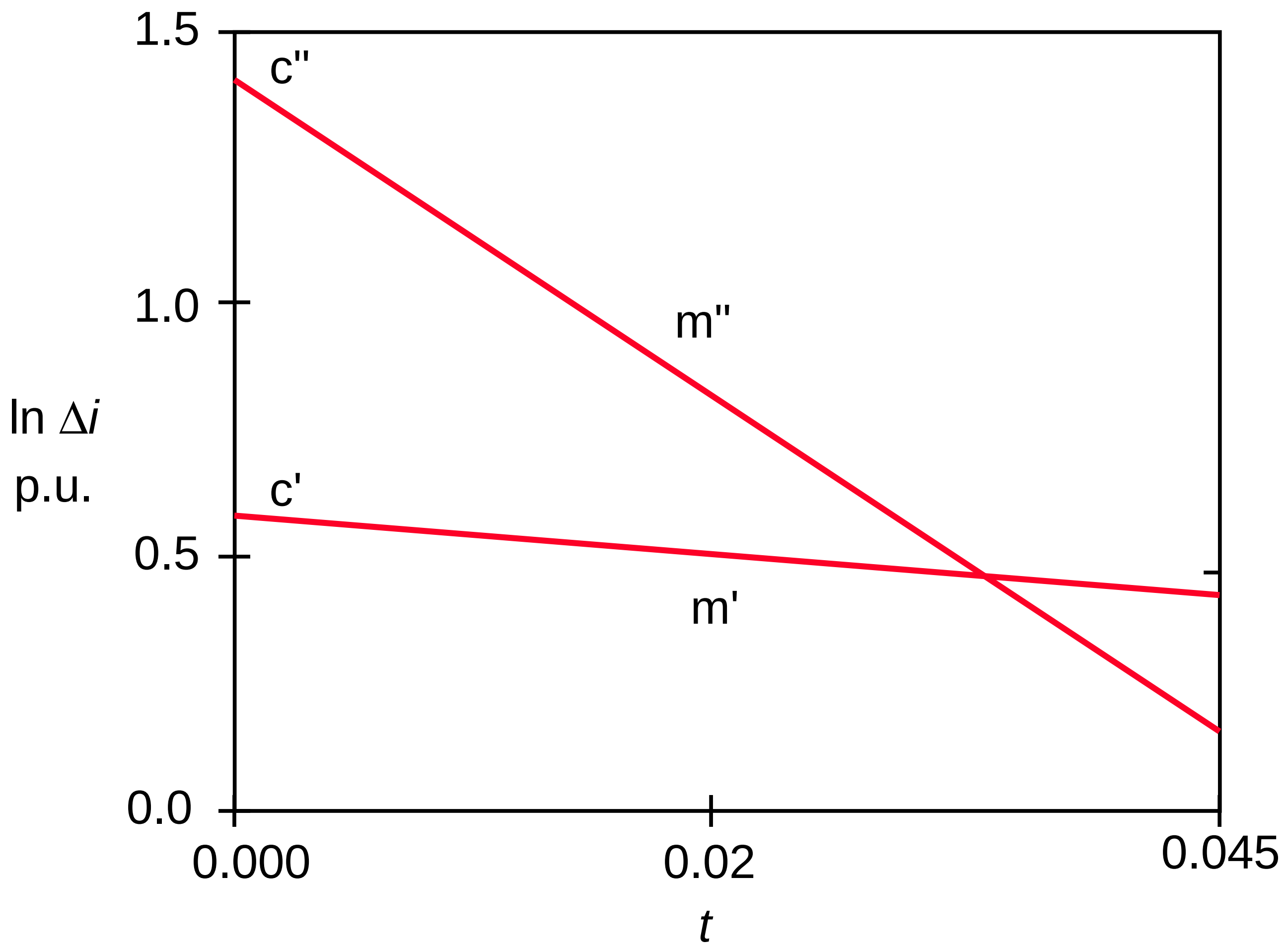
- Third, using the first two cycles of the fault current envelope
  - the steady state and transient currents are subtracted from the subtransient current
  - the logarithmic curve of the envelope is plotted with respect to linear time as a straight line
  - the y-intercept and the slope are obtained from the graph

$$\Delta i' = \left(I''_d - I'_d\right) e^{-t/\tau''_d}$$

$$\ln \Delta i'' = \ln\left(I''_d - I'_d\right) - t/\tau''_d = c'' - m''\,t$$

$$I''_d = e^{c''} + I'_d \qquad X''_d = \frac{E_0}{I''_d} \qquad \tau''_d = \frac{1}{m''}$$

Determining the Transient Constants



Determining the Transient Constants

- **Example**
  - A generator operating at no load, is set to deliver a terminal voltage of 1.0 pu
  - The generator is subjected to a fault on the terminals when phase a is at a voltage peak
  - Peak values of the current are recorded at the following times:
    - 0.0042 s : I = 8.7569
    - 0.0208 s : I = 6.7363
    - 0.3208 s : I = 2.8893
    - 0.3375 s : I = 2.8608
    - 5.0000 s : I = 1.1785
  - Determine the reactances and time constants

Effects of Load Current

- **Pre-fault load currents supplied by the generator affect the generator's behavior during a fault**
- **Two methodologies may be used in the solution process for balanced 3-phase faults**
  - Use of internal voltages behind the generator reactances
  - Using Thevenin's theorem and superposition with load currents

Effects of Load Current

- **Internal Voltages behind the generator reactances**
  - When there is a prefault load current, three internal voltages are calculated
    - E'' = the voltage behind the subtransient reactance
    - E' = the voltage behind the transient reactance
    - E = the voltage behind the synchronous reactance
  - The internal voltages are calculated using the voltage drop equation with the load current

$$E'' = V_T + j\,x''_d\,I_L$$

$$E' = V_T + j\,x'_d\,I_L$$

$$E = V_T + j\,x_d\,I_L$$

Effects of Load Current

- **Example**
  - A 220 kV, 100 MVA, 0.8 lagging pf load is connected to a 13.8 kV generator through a *j*0.20 pu generator step-up transformer.

    The generator parameters are:
    $X_d = 1.0$ pu $\qquad X_d' = 0.25$ pu $\qquad X_d'' = 0.12$ pu

    A short circuit occurs at the load terminals.
  - Find the generator transient current including the load current. Use the method of internal voltages.

Effects of Load Current

$$S_L = 100\,\mathrm{MVA} \qquad \phi = (+)\cos^{-1} 0.8 = 36.9^\circ$$

$$S_L = 100\angle 36.9^\circ \qquad S_{Base} = 100\,\mathrm{MVA} \qquad S_L = \frac{100\angle 36.9^\circ}{100} = 1.0\angle 36.9^\circ \ pu$$

$$V_L = 220\angle 0^\circ \ \mathrm{V} \qquad V_{Base} = 220 \ \mathrm{V} \qquad V_L = \frac{220\angle 0^\circ}{220} = 1.0\angle 0^\circ$$

$$I_L = \frac{S_L^*}{V_L^*} = \frac{1.0\angle -36.9^\circ}{1.0\angle 0^\circ} = 1.0\angle -36.9^\circ$$

$$E' = V_L + I_L\left(j\,X_d' + j\,X_{xfmr}\right) = 1.0\angle 0^\circ + \left(1.0\angle -36.9^\circ\right)\left(j0.25 + j0.20\right)$$

$$= 1.27 + j\,0.36 = 1.32\angle 15.8^\circ$$

$$I_f = \frac{E'}{j\,X_d' + j\,X_{xfmr}} = \frac{1.32\angle 15.8^\circ}{j0.25 + j0.20} = 2.93\angle -74.2^\circ$$

Effects of Load Current

- **Using Thevenin's theorem and superposition with the load current**
  - The fault current is found without the load in the circuit by obtaining the Thevenin's equivalent circuit (original method)
  - The load current is added to the no-load fault current

Effects of Load Current

- **Example**
  - A 220 kV, 100 MVA, 0.8 lagging pf load is connected to a 13.8 kV generator through a *j*0.20 pu GSU transformer.

    The generator parameters are:
    $X_d = 1.0$ pu $X_d' = 0.25$ pu $X_d'' = 0.12$ pu

    A short circuit occurs at the load terminals.
  - Find the generator transient current including the load current. Use the method of Thevenin's theorem and superposition.

Example

$$V_{Th} = 220\angle 0^\circ \text{ V} \qquad V_{Base} = 220 \text{ V} \qquad V_{Th} = \frac{220\angle 0^\circ}{220} = 1.0\angle 0^\circ$$

$$Z_{Th} = j\,X'_d + j\,X_{xfmr} = j0.25 + j0.20 = j0.45$$

$$I'_f = \frac{V_{Th}}{Z_{Th}} = \frac{1.0\angle 0^\circ}{j0.45} = -j2.222$$

$$I_L = \frac{S_L^*}{V_L^*} = \frac{1.0\angle -36.9^\circ}{1.0\angle 0^\circ} = 1.0\angle -36.9^\circ$$

$$I_f = I'_f + I_L = -j2.222 + 1.0\angle -36.9^\circ = -j2.222 + 0.8 - j0.6$$

$$= 0.8 - j2.822 = 2.93\angle -74.2^\circ$$