First Course on Power Systems

Module 10: Transient and Dynamic Stability

By
Ned Mohan
Professor of ECE
University of Minnesota

Reference Textbook:
First Course on Power Systems by Ned Mohan, www.mnpere.com

Module 10: Transient and Dynamic Stability

Introduction

- Thousands of generators operate in Synchronism
- Transient Stability: Otherwise, a major disturbance can cause a generator to go out of Synchronism
- Enough damping to maintain Dynamic Stability

One-Machine Infinite-Bus System

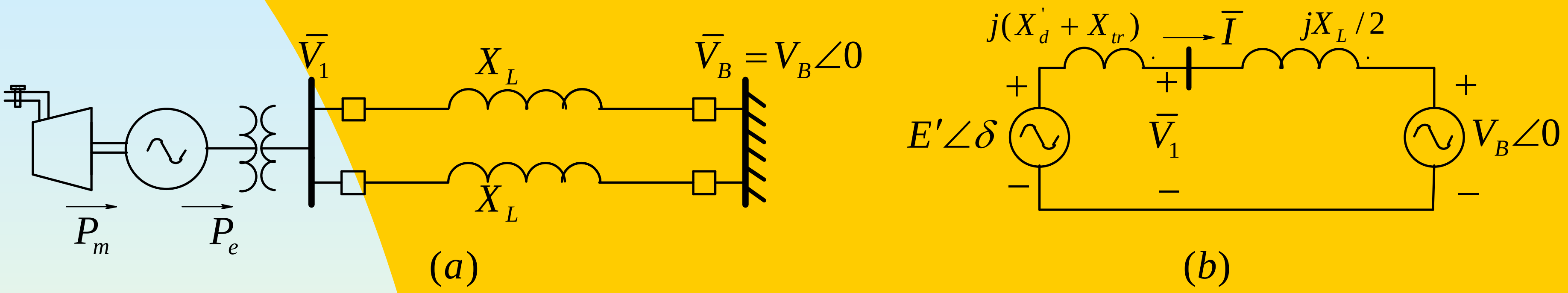


Fig. 11-1 Simple one-generator system connected to an infinite bus.

- **Constant Flux Model**
- **Constant Voltage Magnitude**

$$P_e = \frac{E'V_B}{X_{T1}}\sin\delta$$

Power-Angle Characteristic in One-Machine Infinite-Bus System

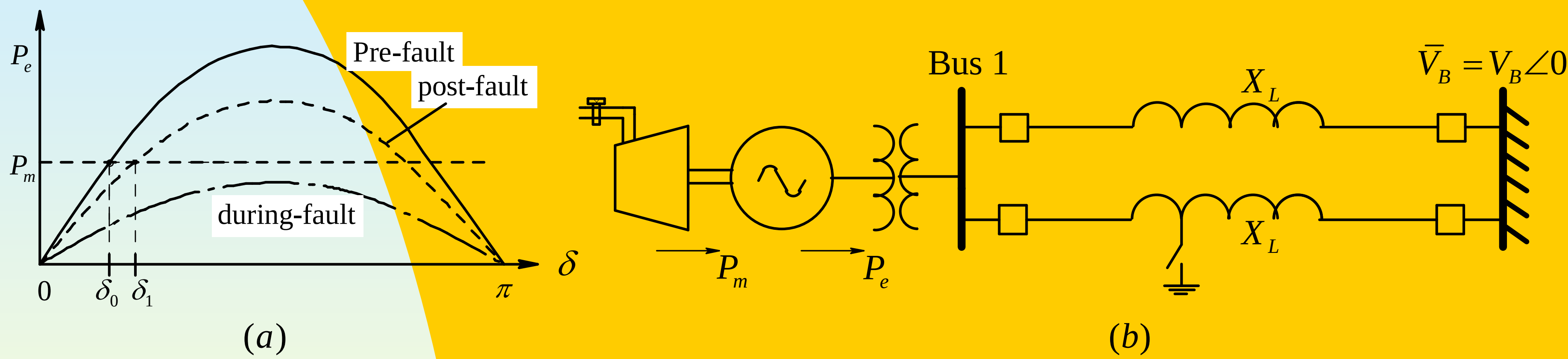


Fig. 11-2 Power-angle characteristics.

Rotor-Angle Swing Following a Fault and a Line Taken Out

$$J_m \frac{d^2\delta_m}{dt^2} = T_m - T_e$$

$$\frac{2H}{\omega_{syn}} \frac{d^2\delta}{dt^2} = P_{m,pu} - P_{e,pu}$$

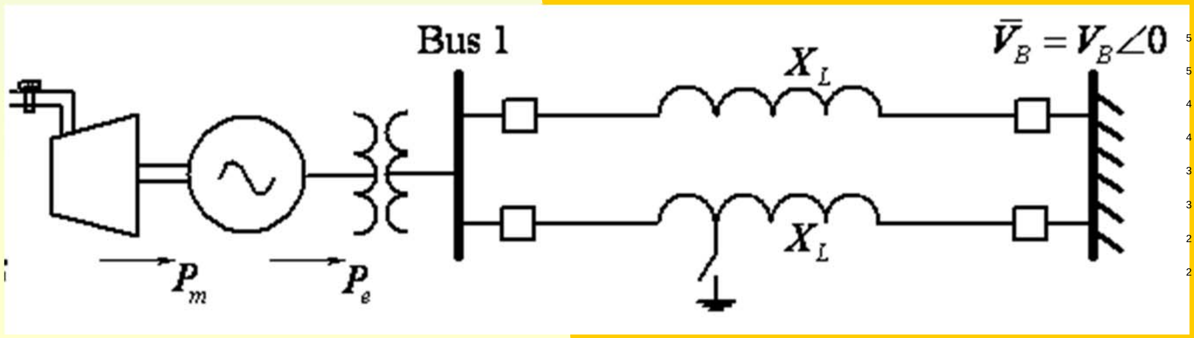
$$H_{gen} = \frac{\frac{1}{2} J_m \omega_{syn,m}^2}{S_{rated,gen}}$$

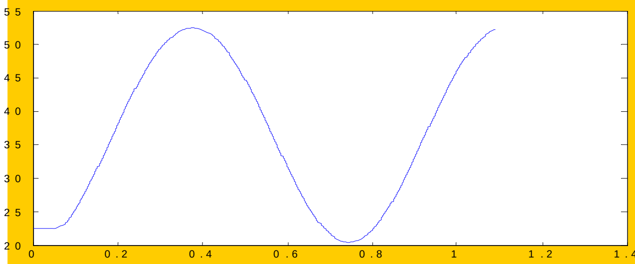
H_{gen} 3-11s for turbo-alternators
1-2s for hydro generators

$$H = H_{gen} \left(\frac{S_{rated,gen}}{S_{system}} \right)$$

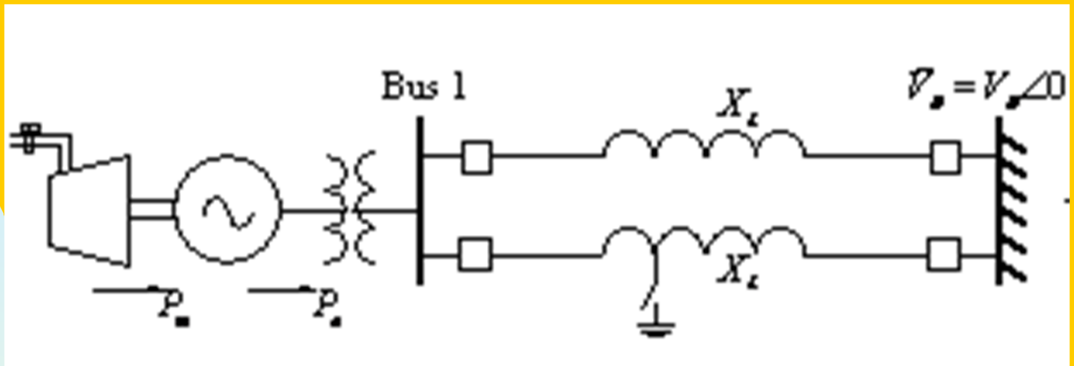
Example 11-1 Consider a simple system discussed earlier in Fig. 11-2b. The infinite-bus voltage is $\bar{V}_B = 1\angle 0\,\text{pu}$. The bus 1 voltage magnitude is $V_1 = 1.05\,\text{pu}$. The generator has a transient reactance $X_d^{'} = 0.28\,\text{pu}$ at a base of 22 kV (L-L) and 1,500 MVA. On the generator base, $H_{gen} = 3.5s$. The transformer has a leakage reactance of $X_{tr} = 0.2\,\text{pu}$ at a base of 345 kV (L-L) and 1,500 MVA. The two 345-kV transmission lines are 100 km in length, and each has a series reactance of $0.367\Omega / km$, where the series resistance and the shunt capacitances are neglected. Initially, the three-phase power flow from the generator to the infinite-bus is 1500 MW.

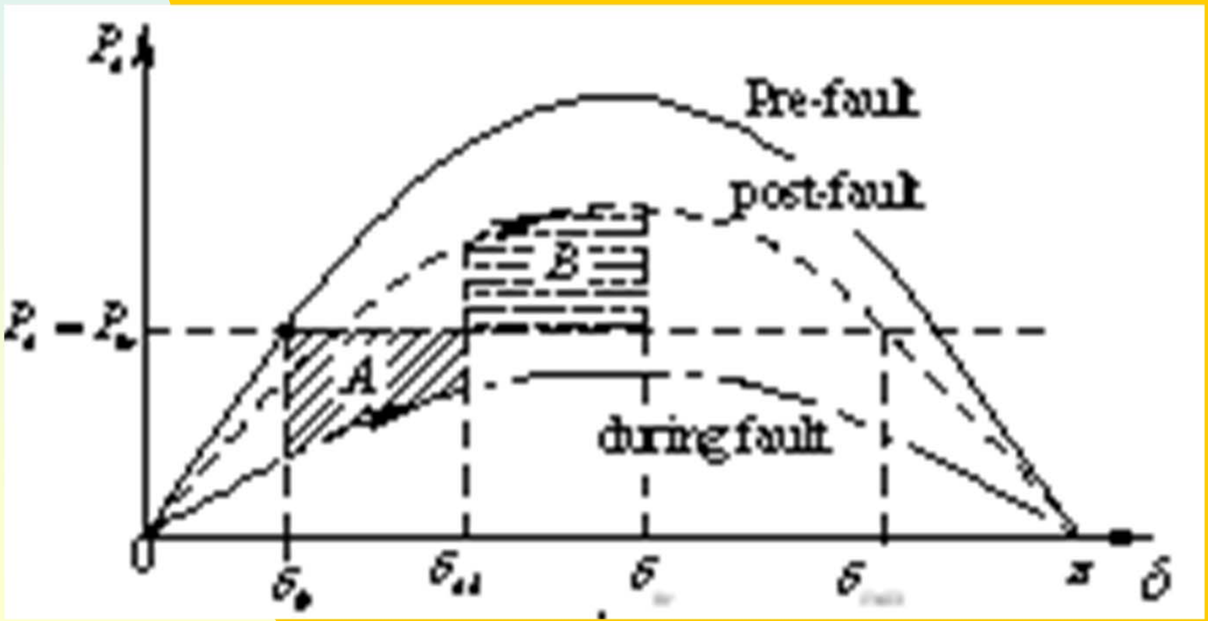
A 3-phase to ground fault occurs on one of the lines, 20 percent of the distance away from bus-1. Calculate the maximum rotor-angle swing δ_m if the fault clearing is 40 ms after which the faulted transmission line is isolated from the system by the circuit breakers at both ends of the line.



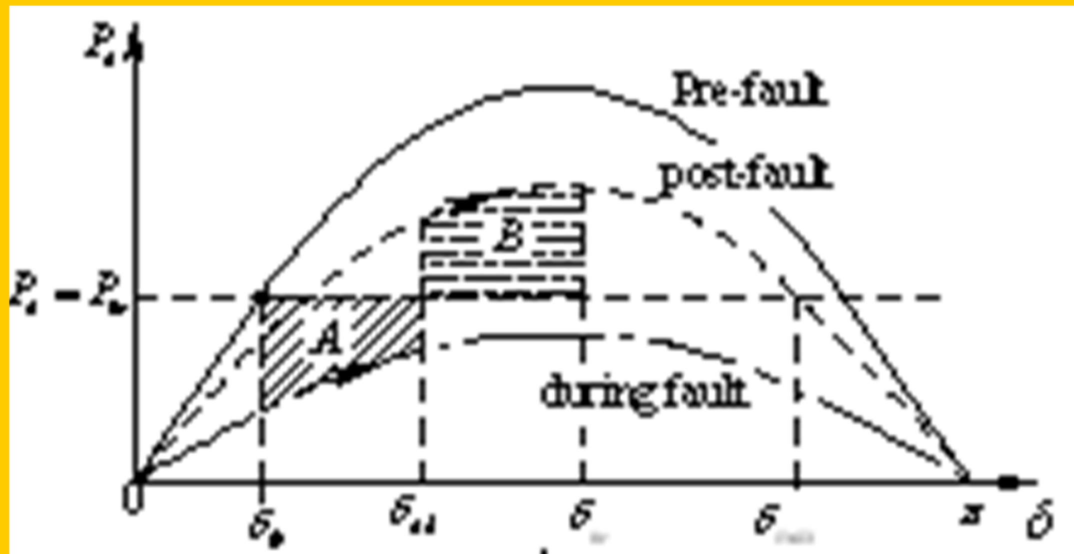


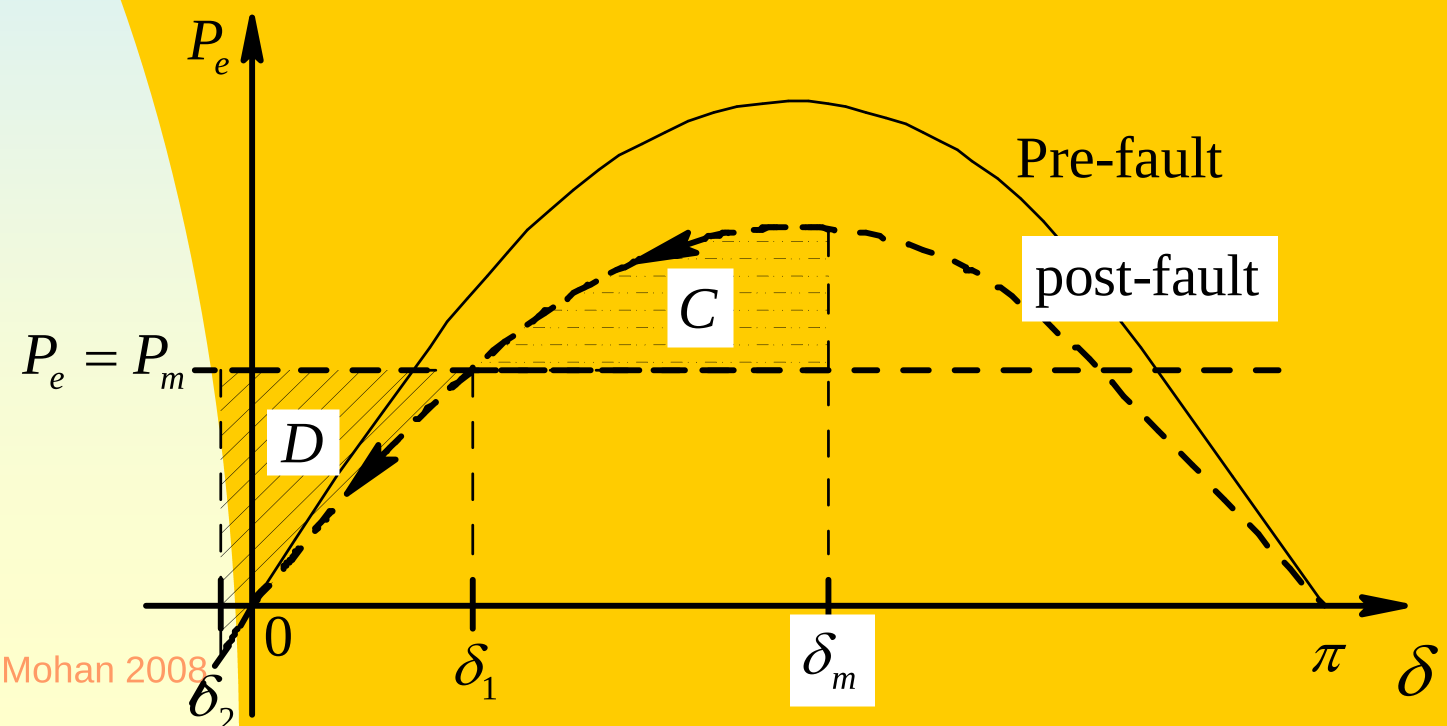
Determining Transient Stability using Equal-Area Criterion





Rotor Oscillations After the Fault is Cleared





Critical Clearing Angle using Equal-Area Criterion

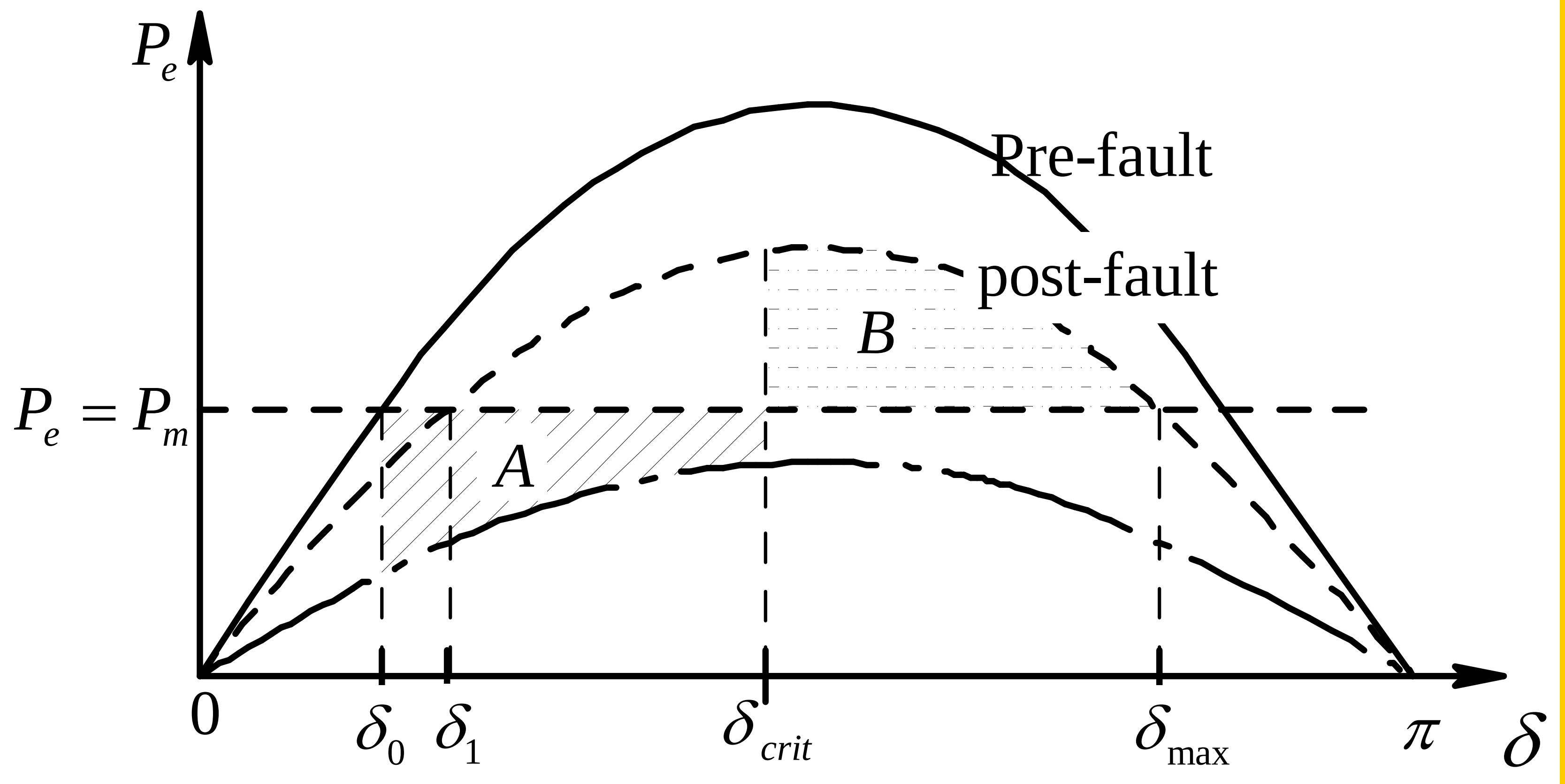
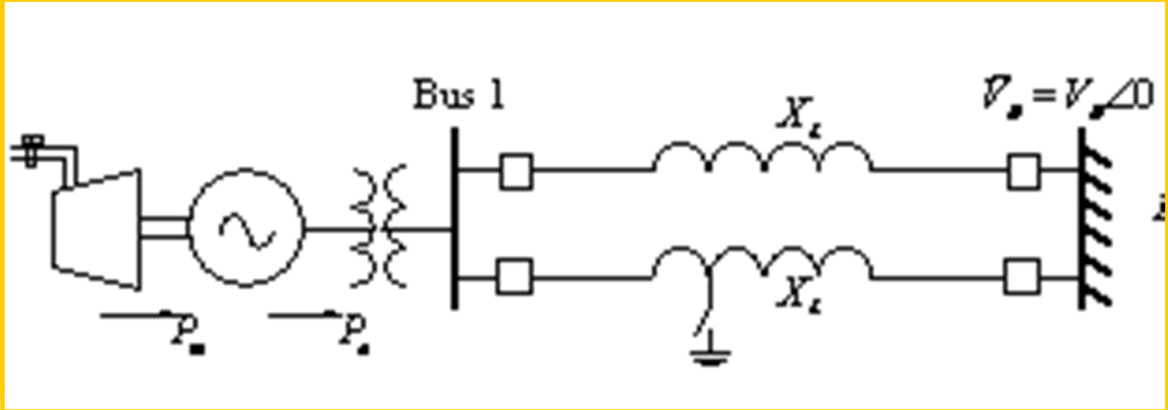


Fig. 11-6 Critical clearing angle.

Example using Equal-Area Criterion

Example 11-2 Consider a simple system discussed earlier in Fig. 11-4a. The infinite-bus voltage is $\bar{V}_B = 1\angle 0\,\text{pu}$. The voltage magnitude at Bus 1 is $V_1 = 1.05\,\text{pu}$. The generator has a transient reactance $X_d^{'} = 0.28\,\text{pu}$ at a base of 22 kV (L-L) and 1,500 MVA. On the generator base, $H_{gen} = 3.5\,s$. The transformer has a leakage reactance of $X_{tr} = 0.2\,\text{pu}$ at a base of 345 kV (L-L) and 1,500 MVA. The two 345-kV transmission lines are 100 km in length, and each has a series reactance of $0.367\,\Omega/km$, where the series resistance and the shunt capacitances are neglected. Initially, the three-phase power flow from the generator to the infinite-bus is 1500 MW.

A 3-phase to ground fault occurs on one of the lines, 20 percent of the distance away from bus-1. Calculate the maximum rotor-angle swing δ_m if the rotor angle at the time of fault clearing is 75^0.



Solution to Example 11-2:

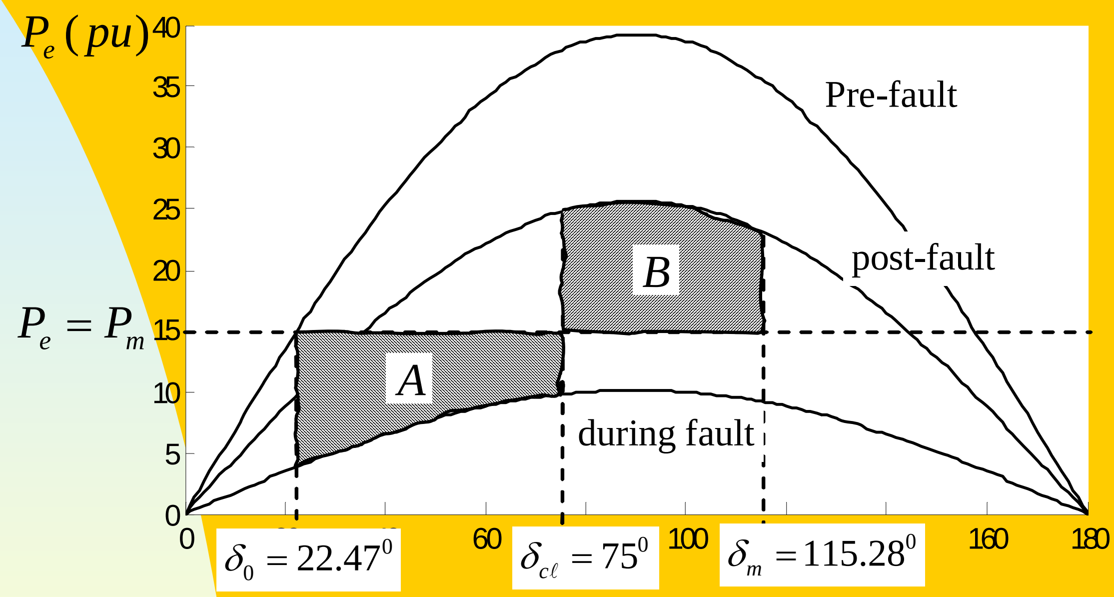


Fig. 11-7 Power angle curves and equal-area criterion in Example 11-2.