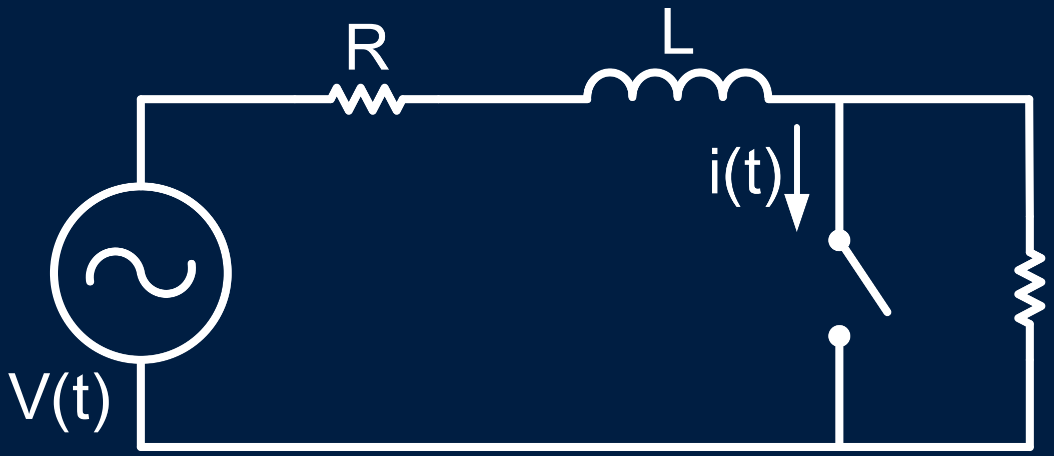
Fault Currents, Circuit Breakers, and a New Method for X/R Calculations in Parallel Circuits

Amir Norouzi
Schweitzer Engineering Laboratories, Inc.

Outline

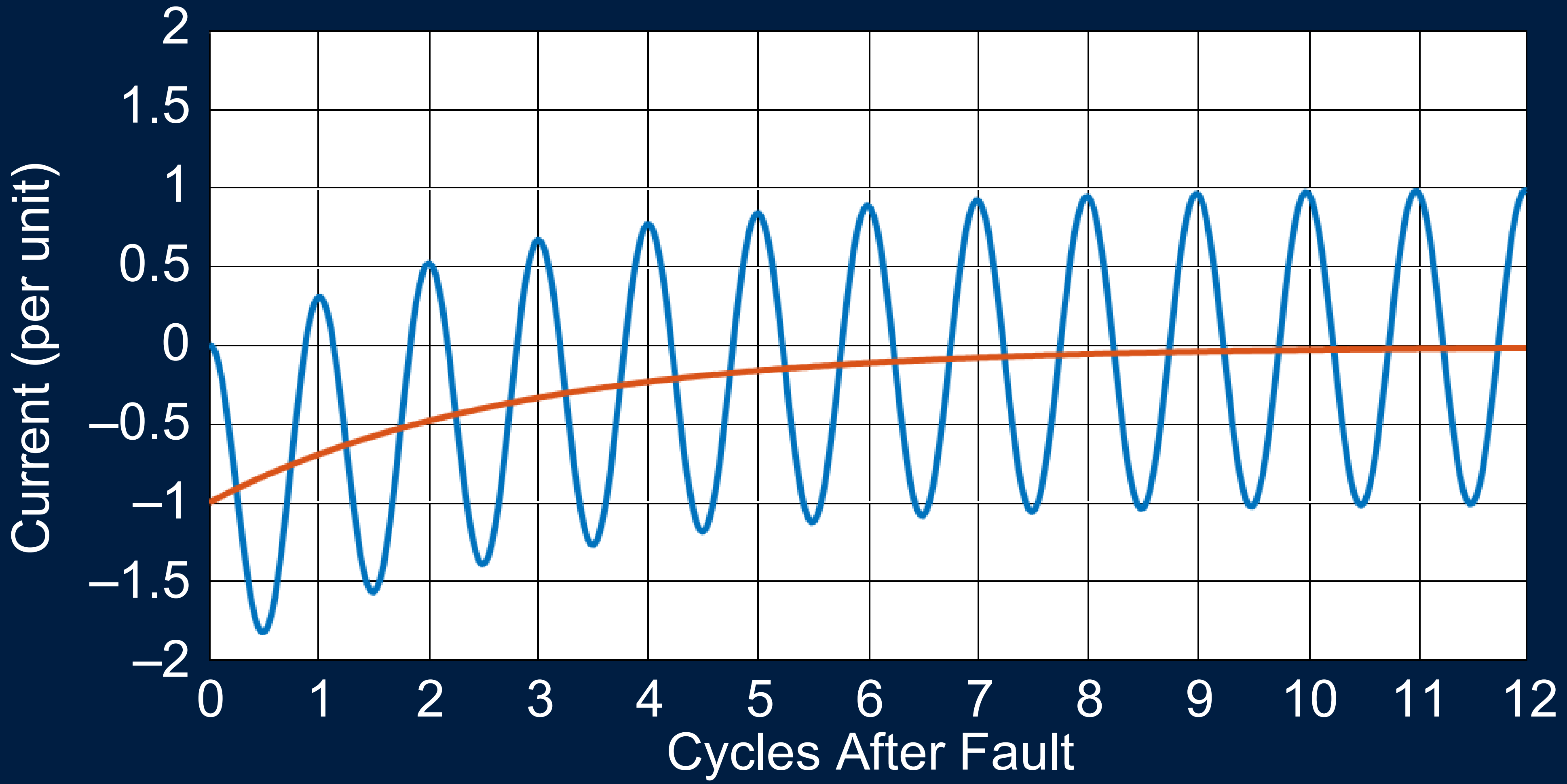
1) Fault Currents and Circuit Breaker Rating
2) Fault Current Characteristics in Parallel Circuits
3) Transient Current Calculation: A General Approach
4) The Concept of a Variable X/R
5) Conclusions

Fault Currents and Circuit Breaker Rating



$$i(t) = \overbrace{\frac{V_m}{Z}\sin(\omega t + \theta - \alpha)}^{\text{steady state}} - \underbrace{\left[\frac{V_m}{Z}\sin(\theta - \alpha) - i(0)\right] e^{\frac{-\omega t}{X/R}}}_{\text{transient}}$$

Fault Currents and Circuit Breaker Rating



Fault Currents and Circuit Breaker Rating

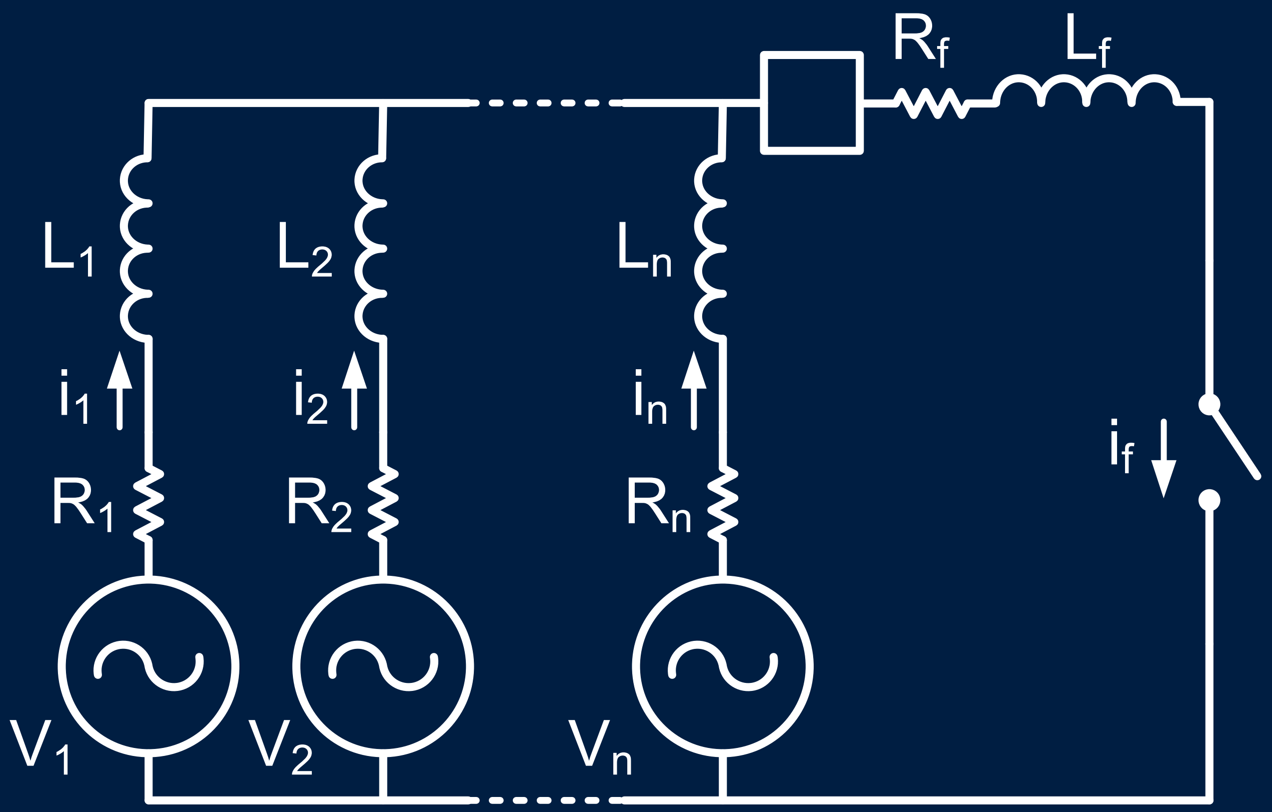
Total *rms* value of the combined ac and dc currents

$$I_{asym} = I_{sym}\sqrt{1 + 2e^{\frac{-2\omega t}{X/R}}}$$

Symmetrical-based rating

$$I_{sym} \text{ and } \frac{X}{R} = 17$$

Fault Current Characteristics in Parallel Circuits



- Transient current consists of *n* components
- $I_1 e^{\alpha_1 t} + I_2 e^{\alpha_2 t} \neq I e^{at} \Rightarrow$ No single X/R can be defined

Fault Current Characteristics in Parallel Circuits

- A single X/R cannot provide accurate fault current
- Decaying sinusoidal components may exist

$$\left[I\cos\left(\beta t\right)\right]e^{\alpha t}$$

Transient Current Calculation: A General Approach

- Phasor calculations not adequate
- Need to solve differential equation of fault current
- Direct methods need substantial computing resources

Transient Current Calculation: A General Approach

- Power systems are linear and time-invariant
- ODE solution using algebraic operations

Transient Current Calculation: A General Approach

Key Steps

1) Direct setup of ODE without KVL or KCL

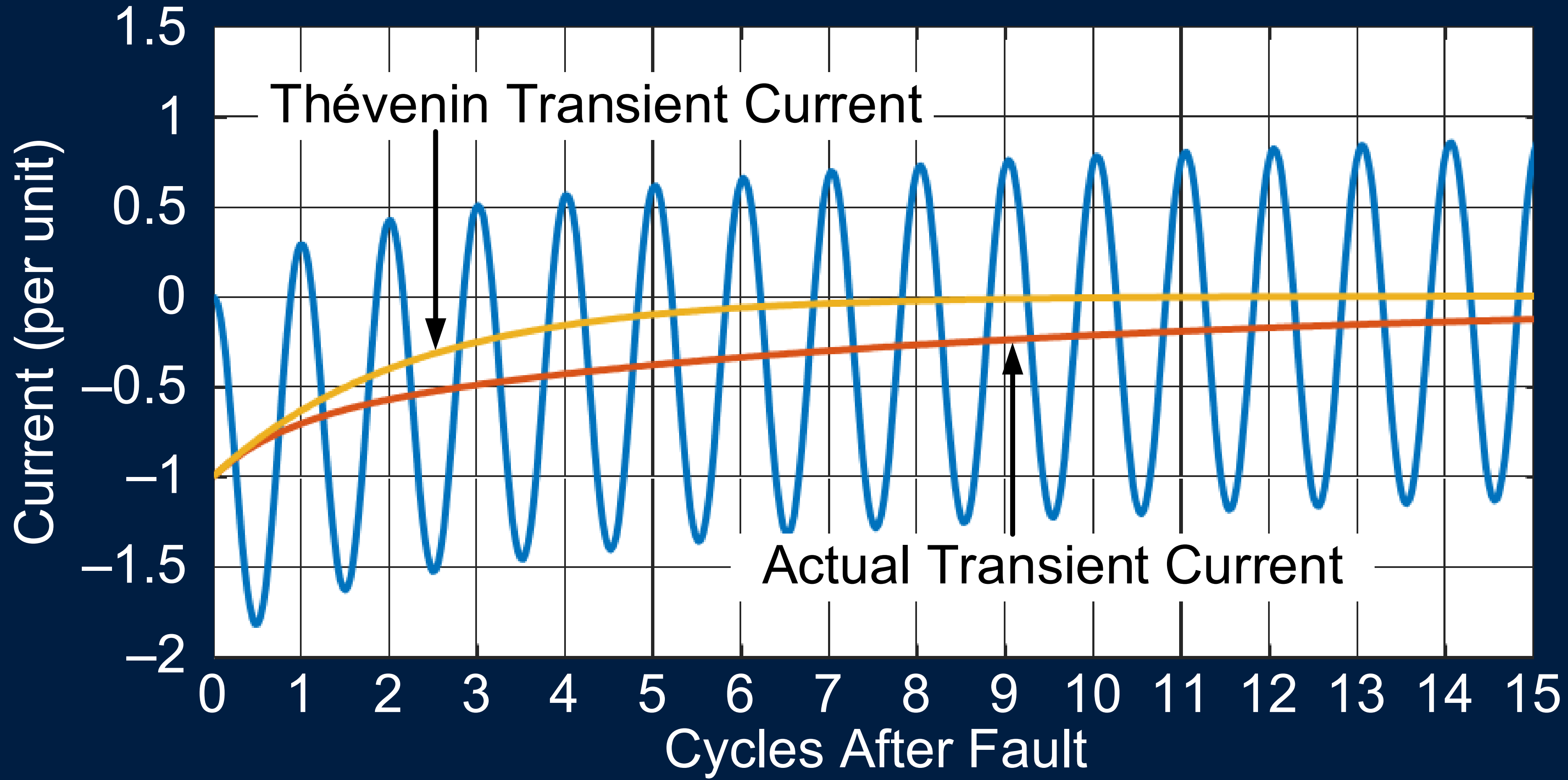
$$\left[\mathrm{I}(s)\right] = \frac{1}{|A|}\left[\mathcal{F}(s)\right] \Rightarrow |A| \text{ will provide the ODE with a pattern}$$

2) Initial conditions calculations

$\mathrm{i}_k(0^+)$ and its $(n-1)$ derivatives need to be calculated

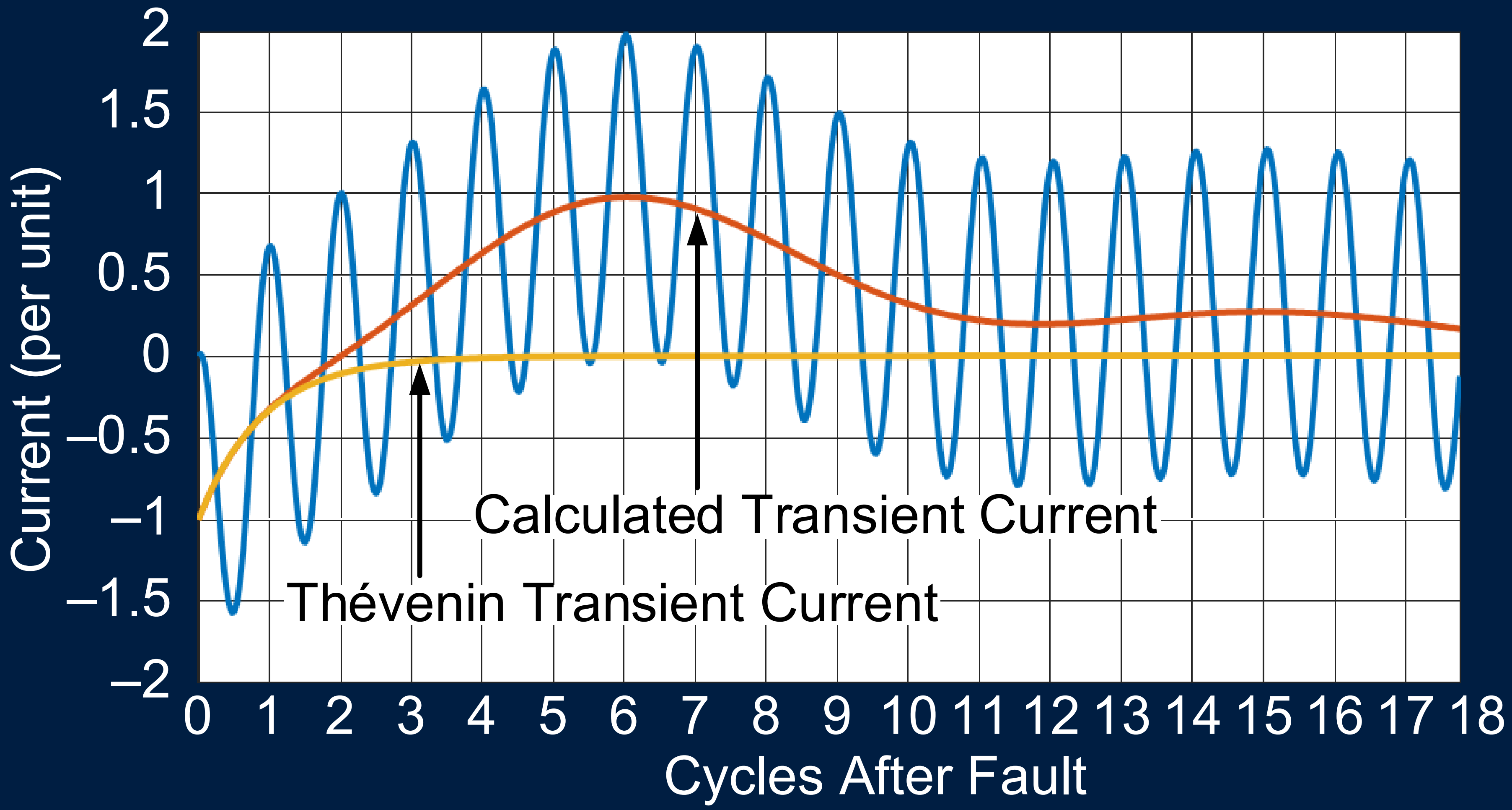
Transient Current Calculation: A General Approach

Example 1: Third Order Circuit



Transient Current Calculation: A General Approach

Example 2: Fourth Order Circuit



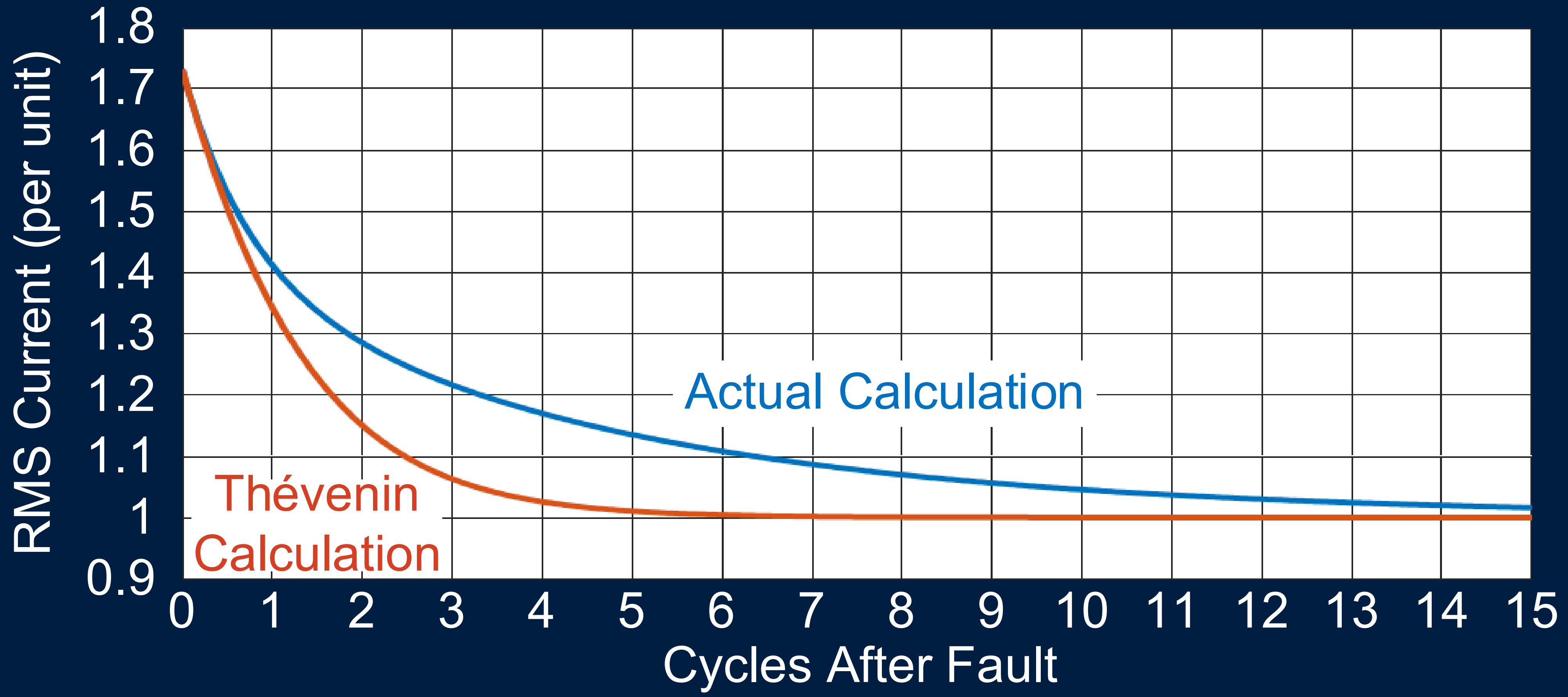
The Concept of a Variable X/R

RMS Value of Combined AC and DC Currents

$$I_{asym} = \sqrt{I_{sym}^2 + I_{tr.}^2}$$

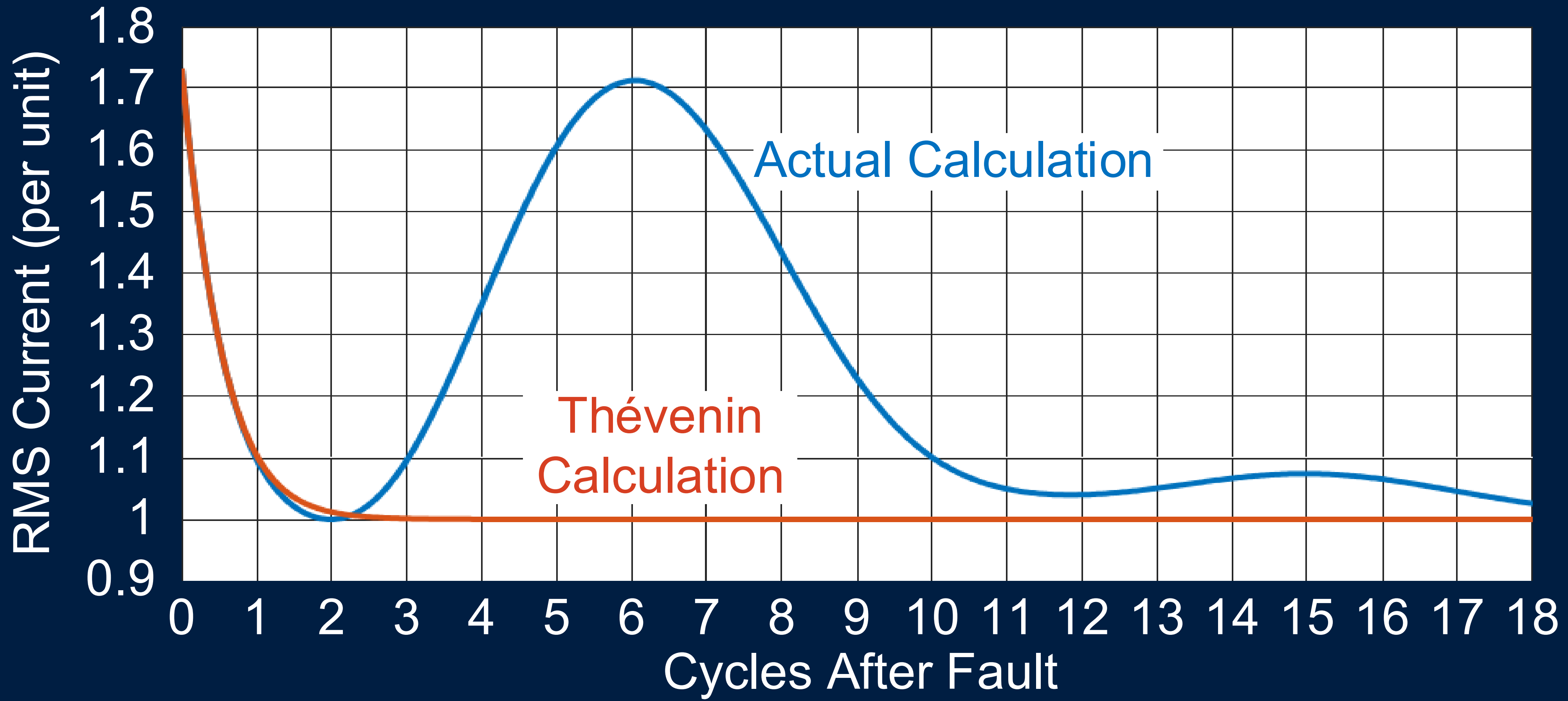
The Concept of a Variable X/R

Total RMS Current of Example 1



The Concept of a Variable X/R

Total RMS Current of Example 2



The Concept of a Variable X/R

Basic Concept

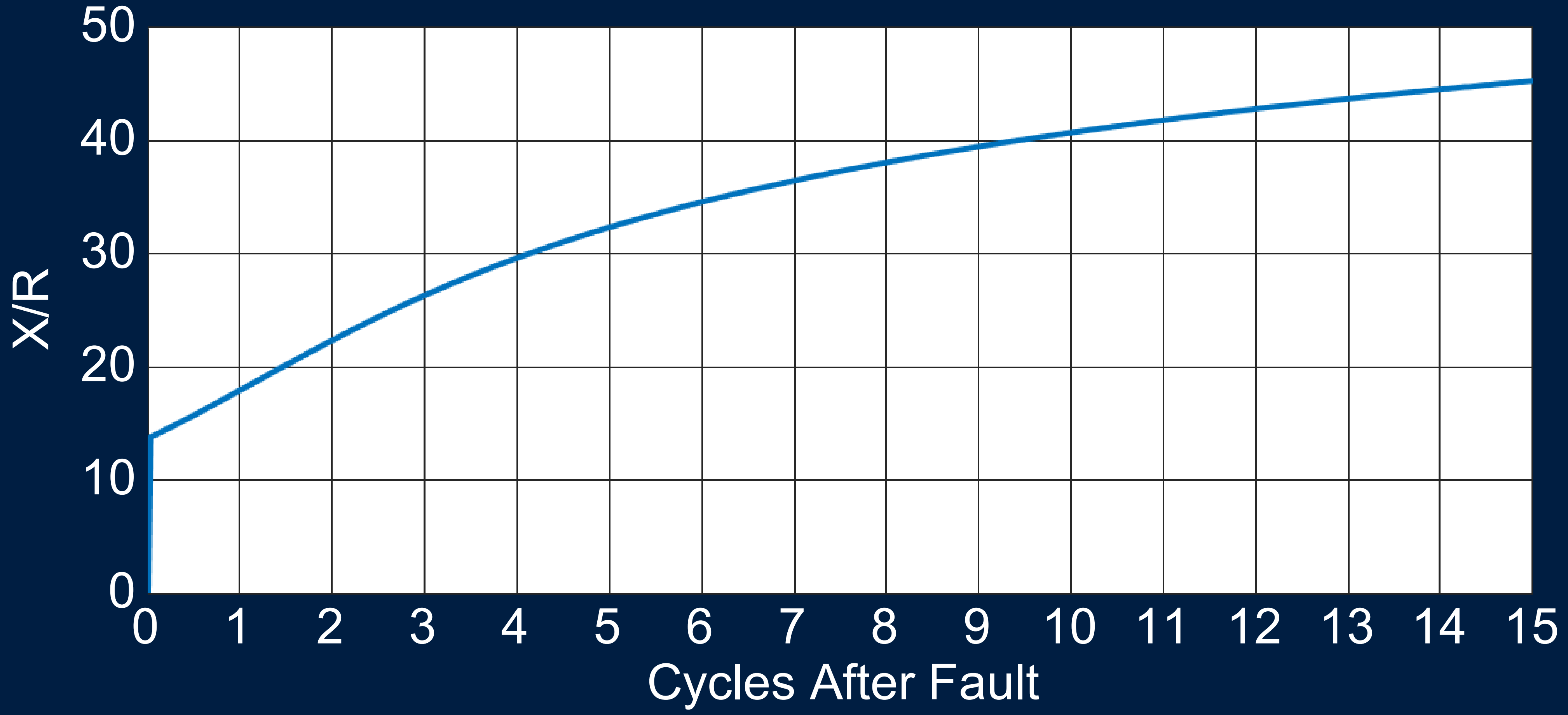
1) Calculate the accurate total *rms* current (I_{asym})

2) Calculate a time-varying X/R from I_{asym} and I_{sym}

$$I_{asym} = I_{sym}\sqrt{1 + 2e^{\frac{-2\omega t}{X/R}}}$$

The Concept of a Variable X/R

Variable X/R in Example 1



Conclusions

- A single X/R not an accurate description of fault current
- Fault’s ODE can be algebraically set up and solved
- A variable X/R links rating standards with actual current

Questions?