

Distance Relay Response to Transformer Energization: Problems and Solutions

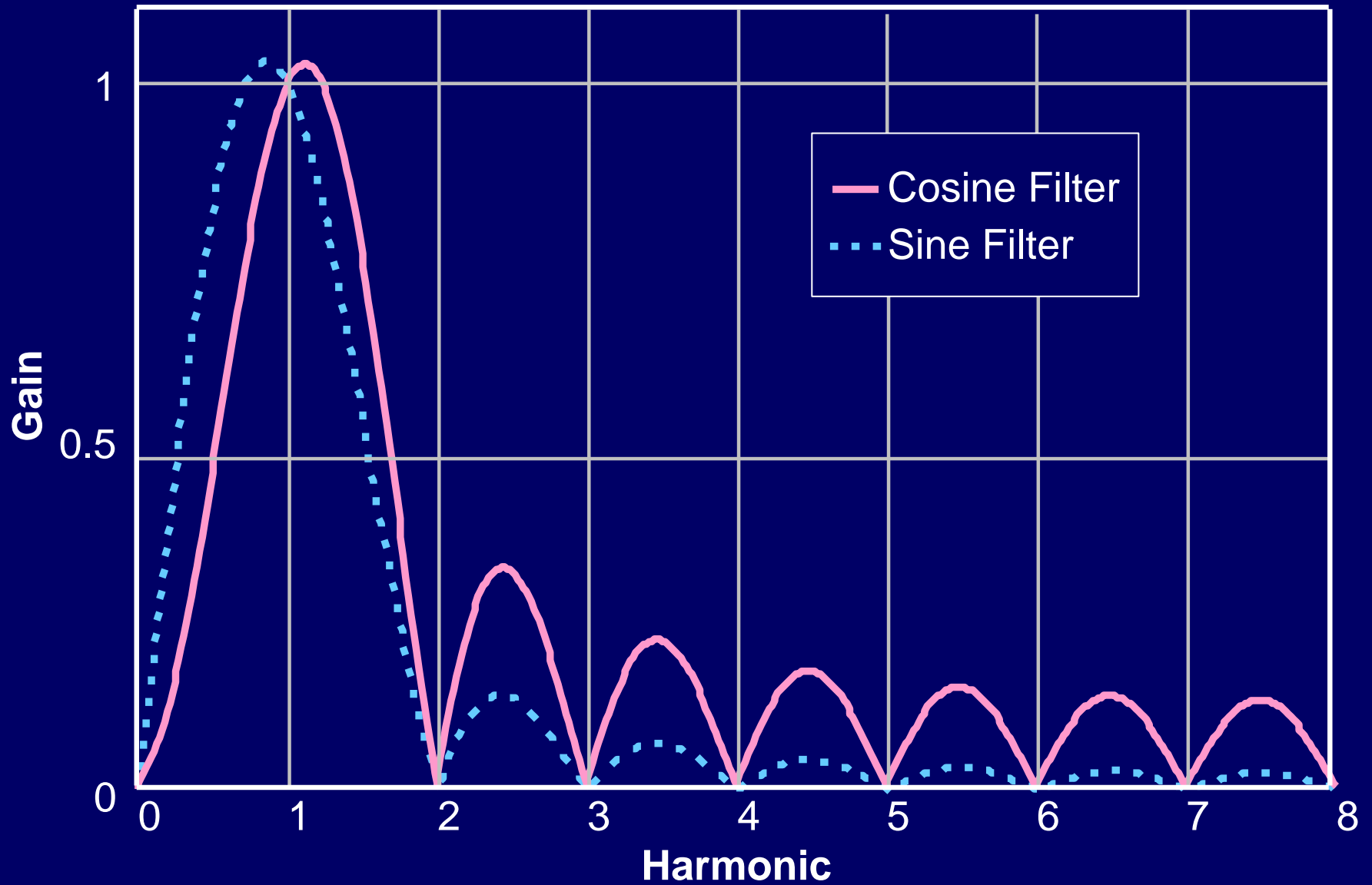
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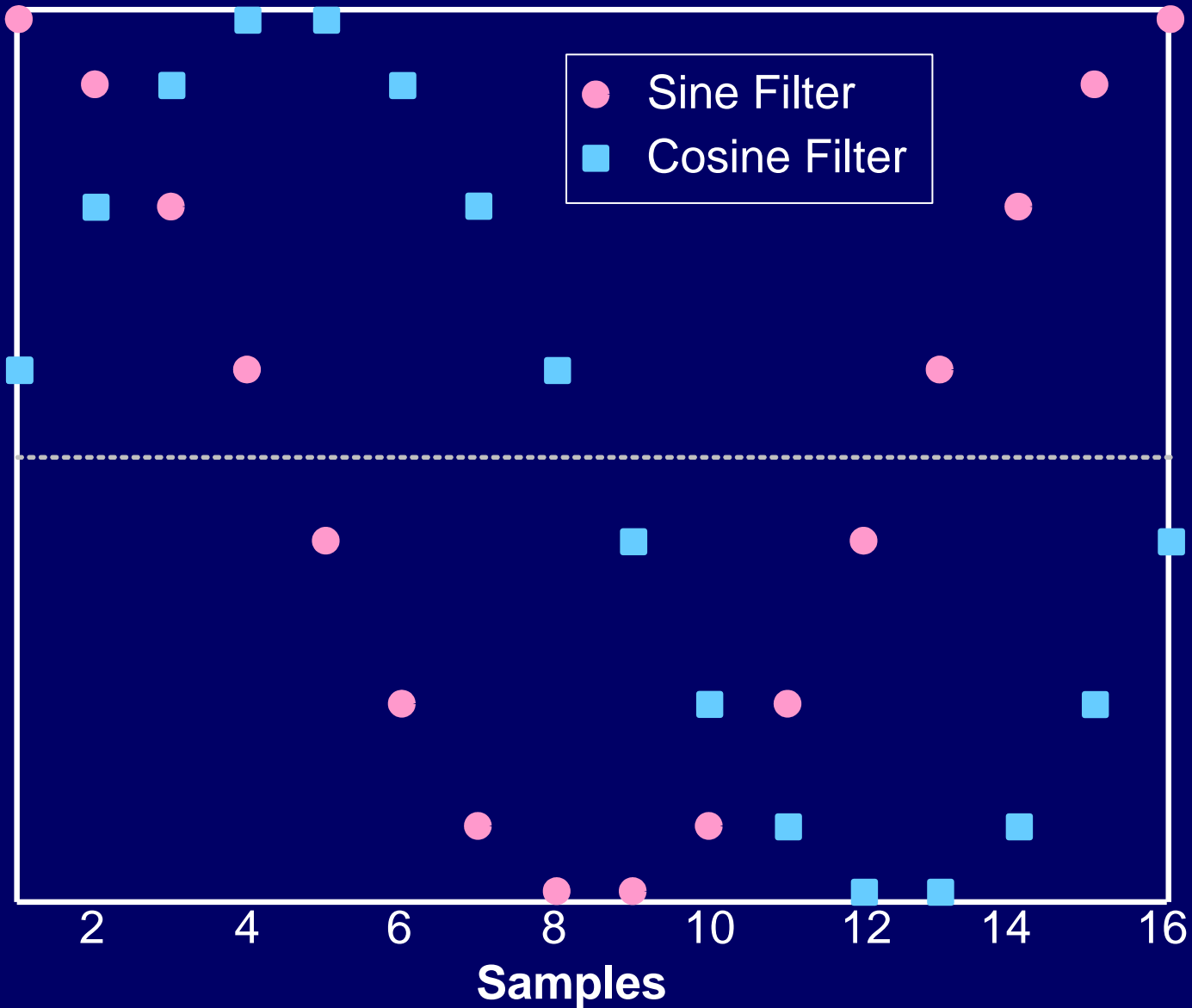
Digital Relay Filtering

- Analog low-pass
 - ◆ Removes high-frequency signals
 - ◆ Anti-aliasing
- Digital filtering
 - ◆ Fundamental frequency
 - ◆ Removes harmonics
 - ◆ Cosine and fourier

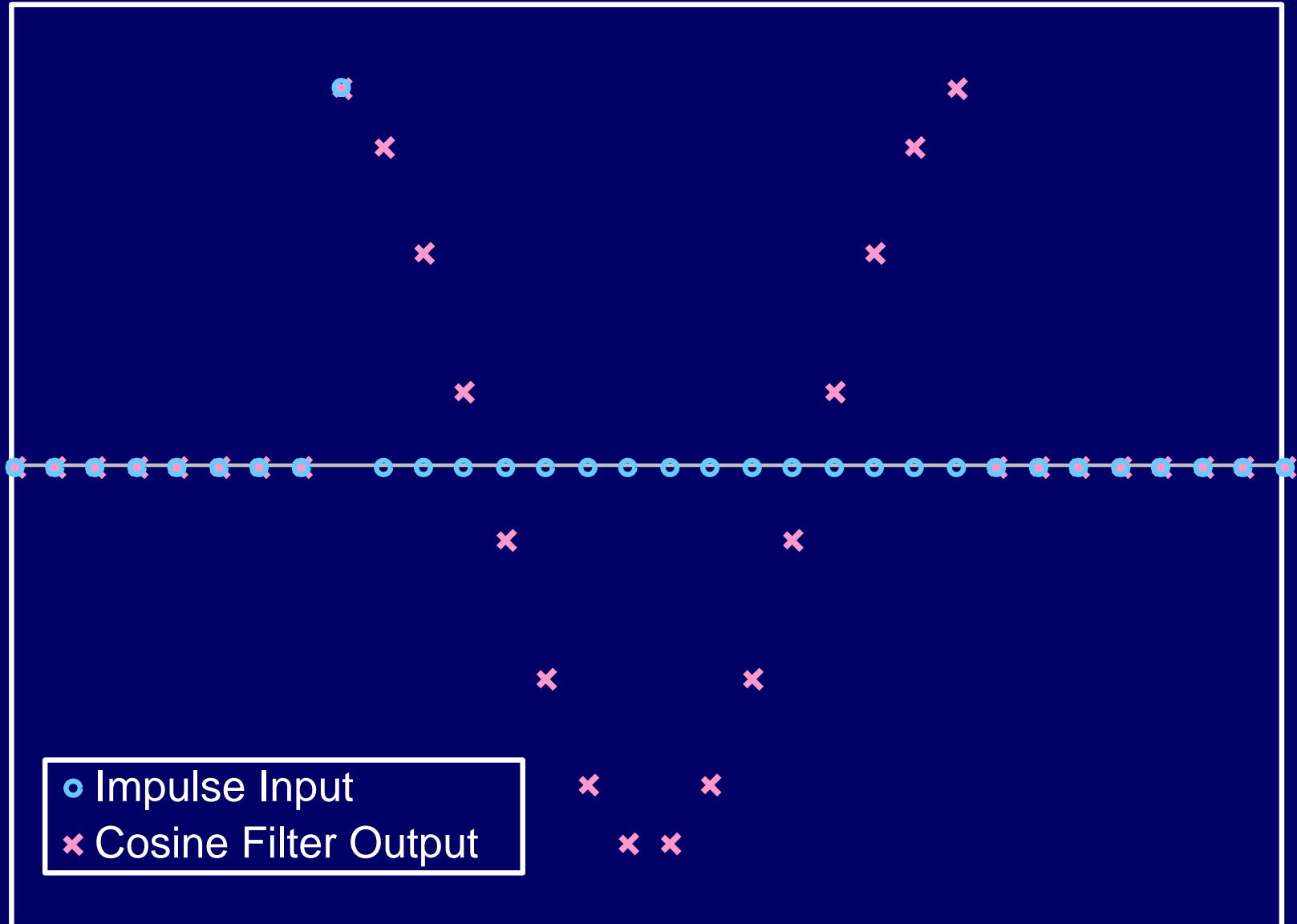
Frequency Response



Filter Coefficients



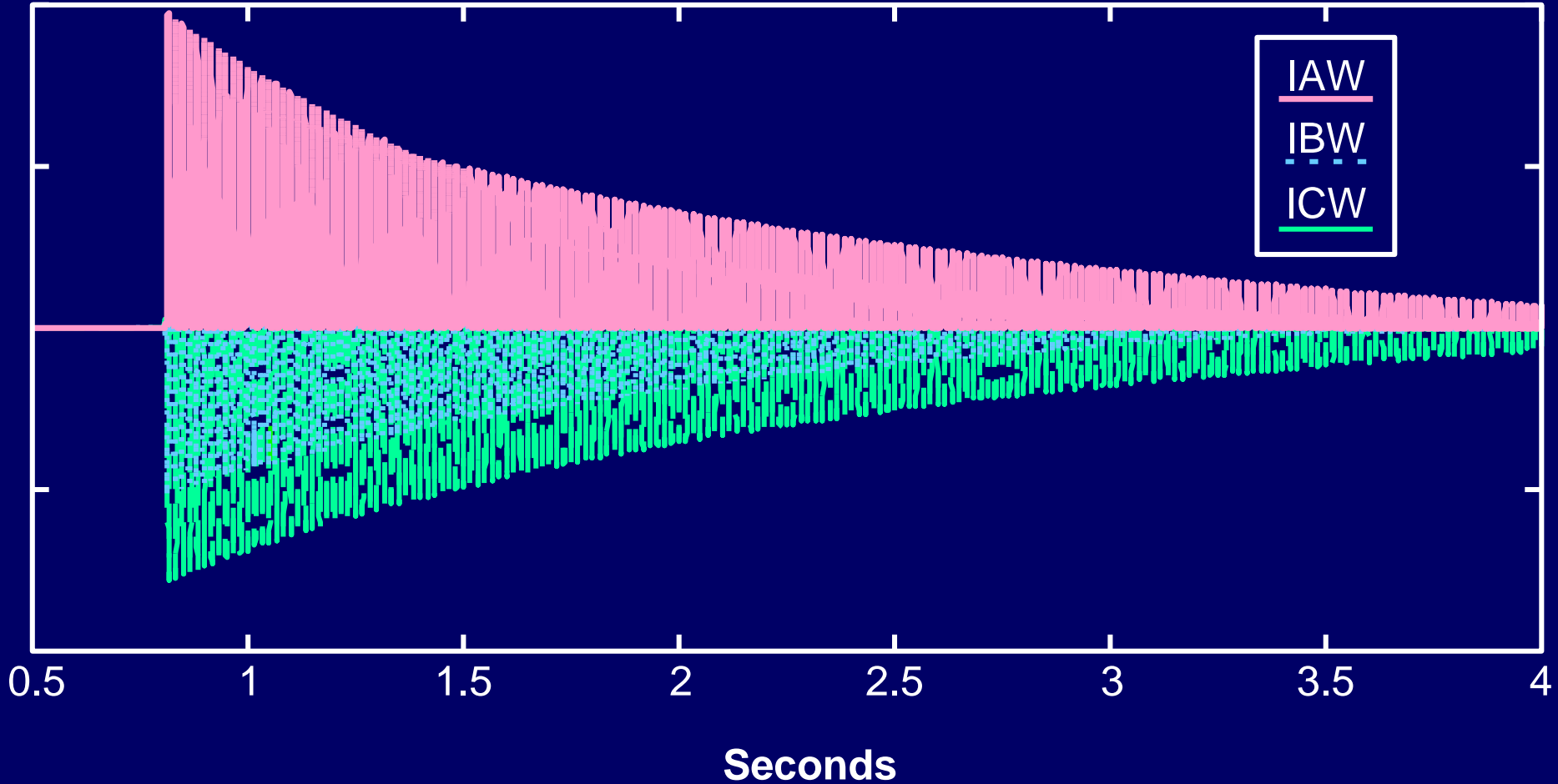
Impulse Response



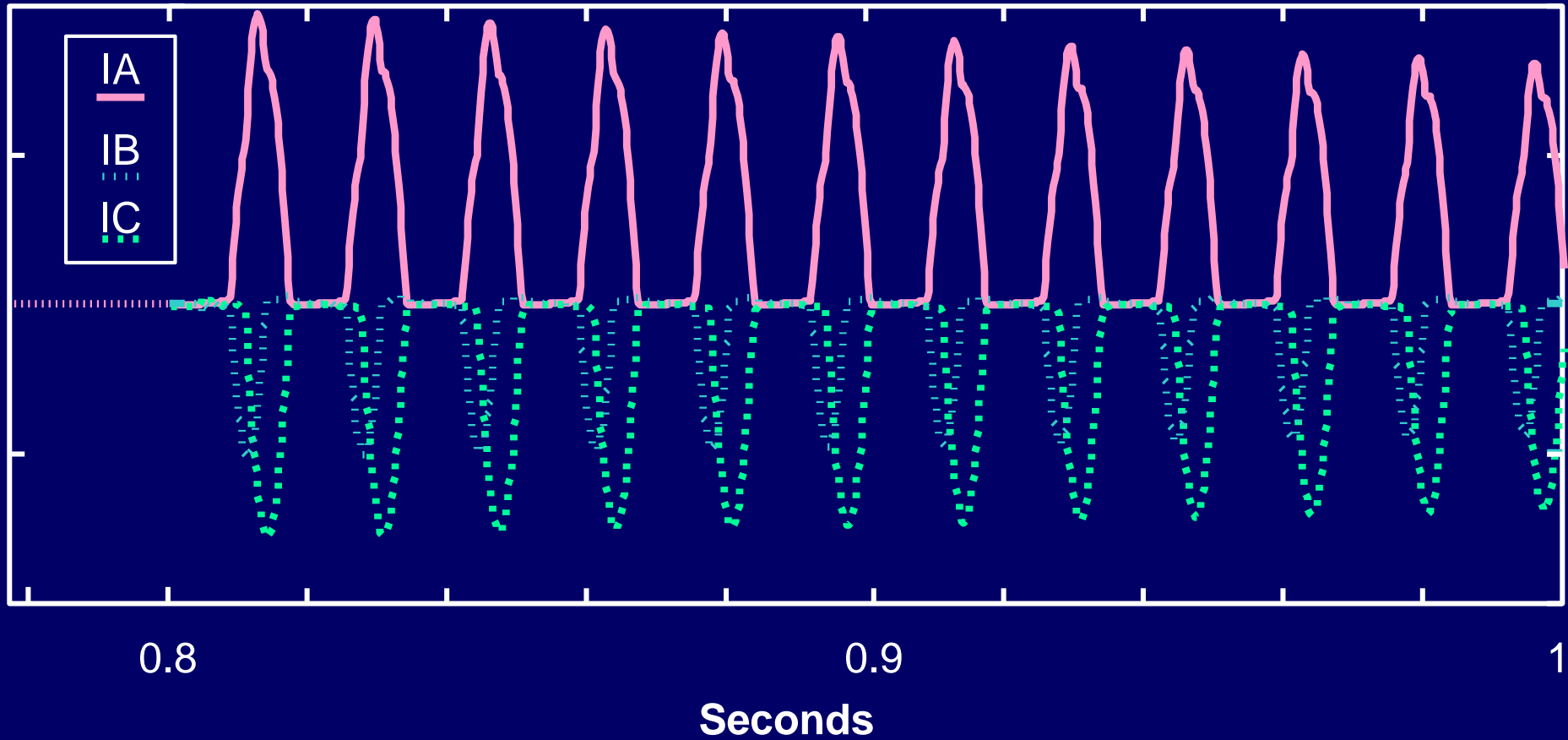
Transformer Inrush

- High harmonic content
- High peak magnitude
- Significant amount of fundamental frequency
- Digital filter extracts fundamental frequency

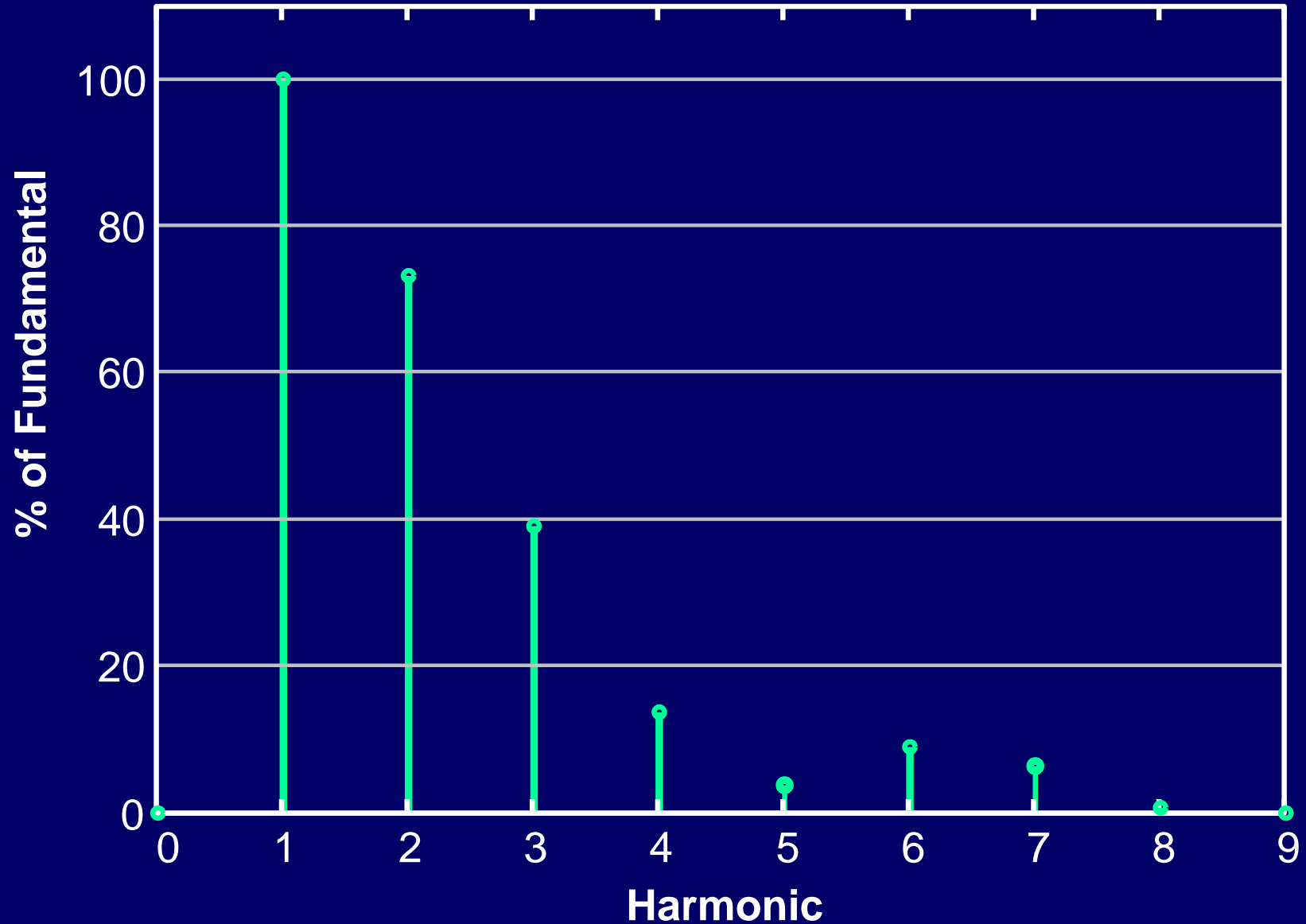
Typical Inrush Waveforms



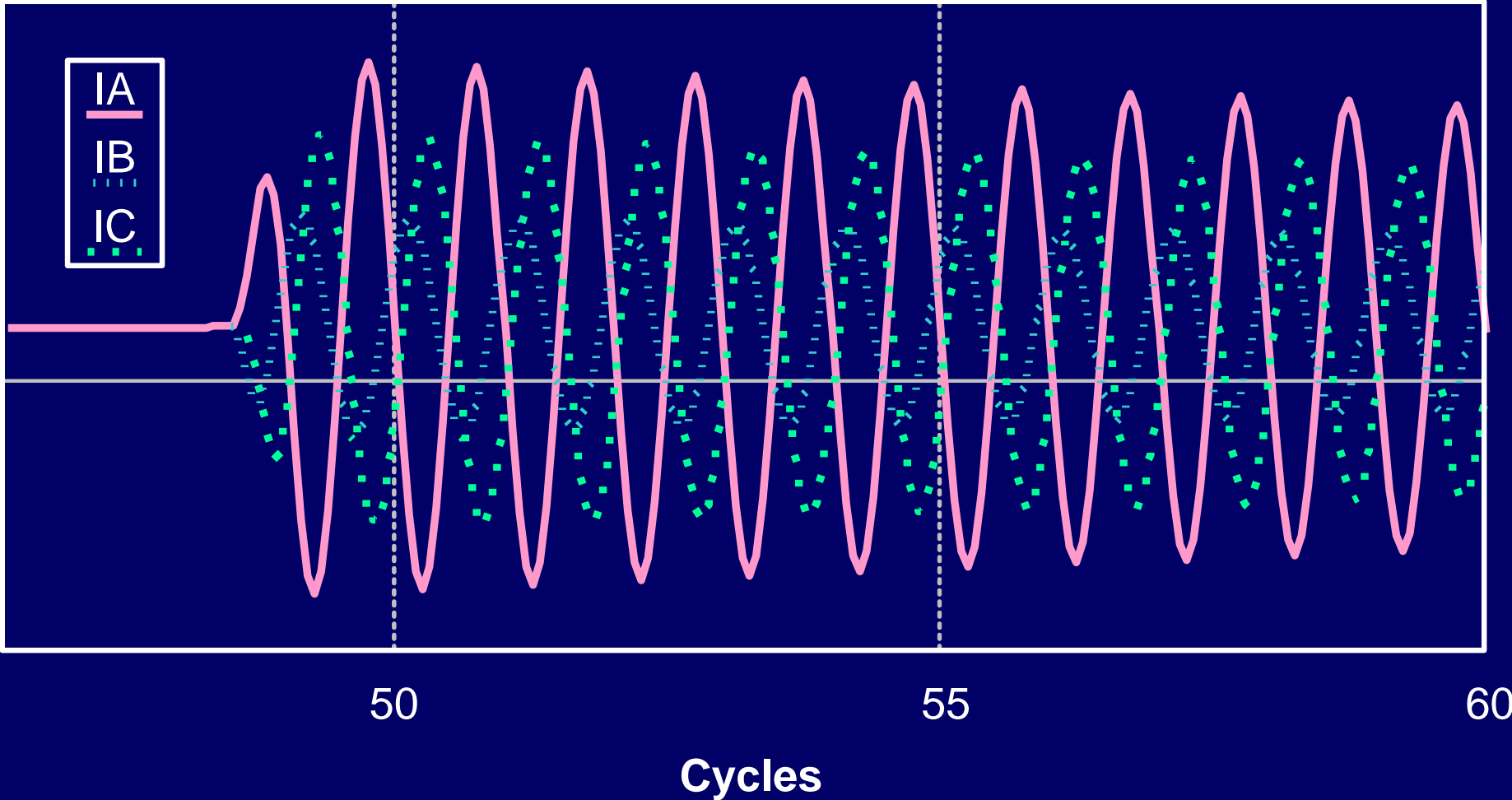
Inrush Currents – Zoomed-in



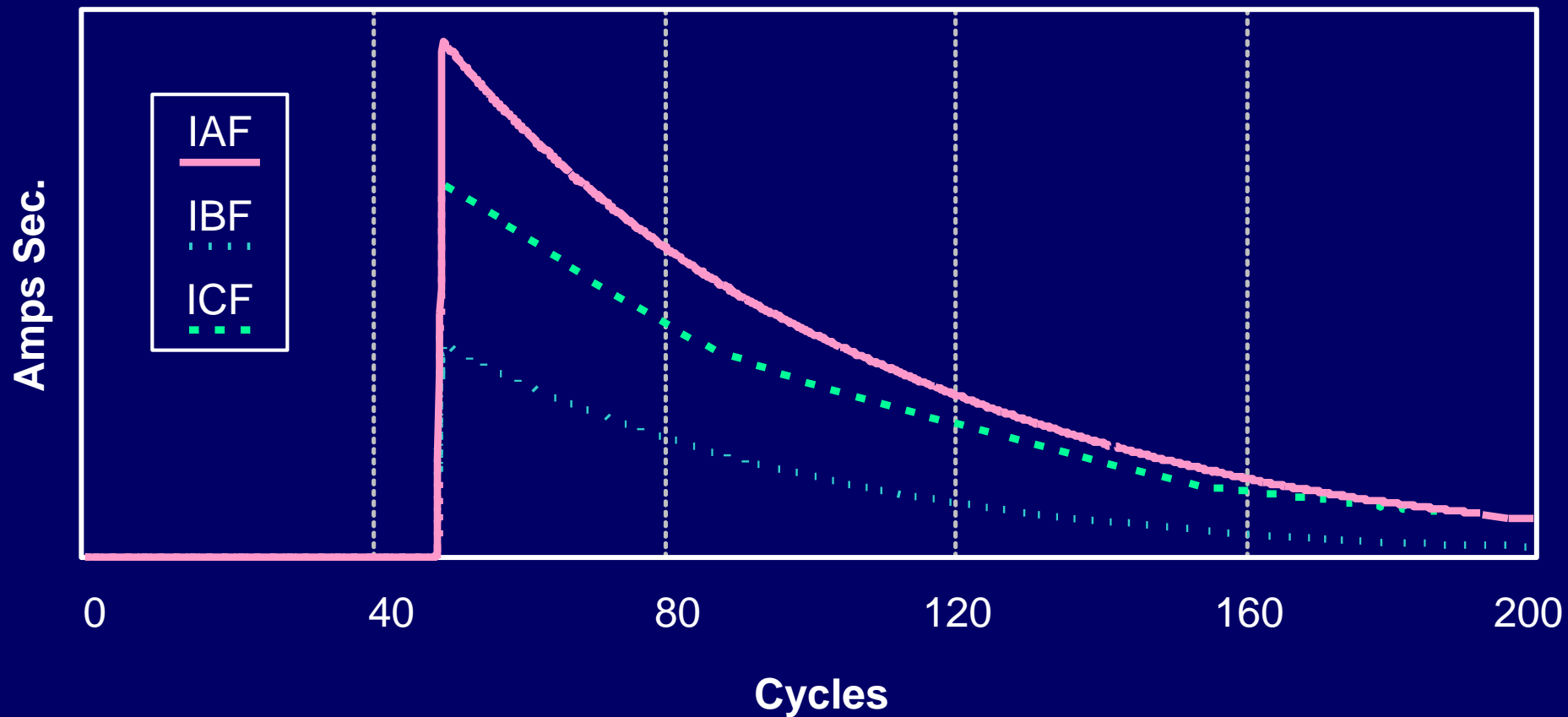
Harmonic Analysis Inrush Currents



Output Full-Cycle Cosine Filter



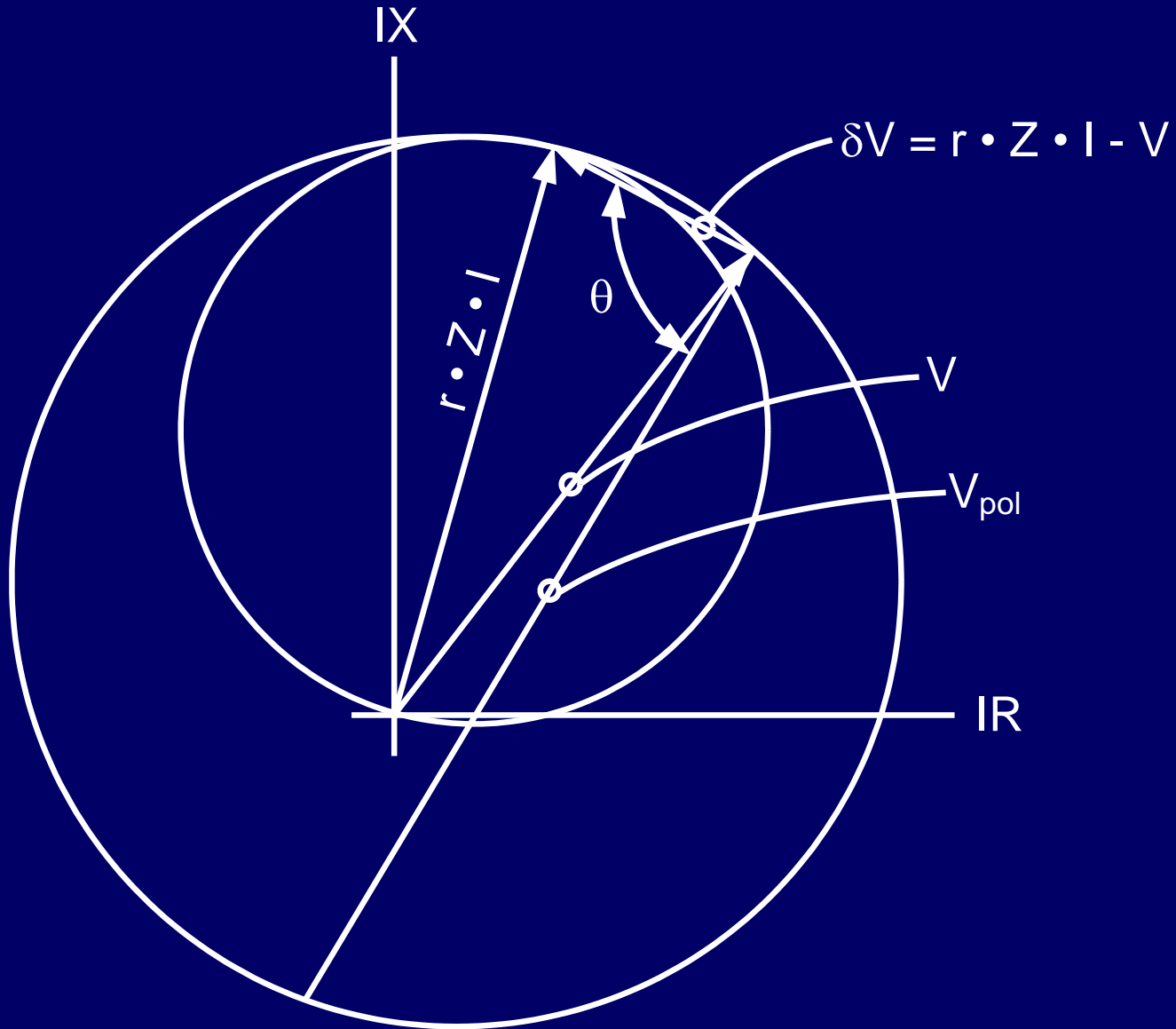
Magnitude of Filtered Currents



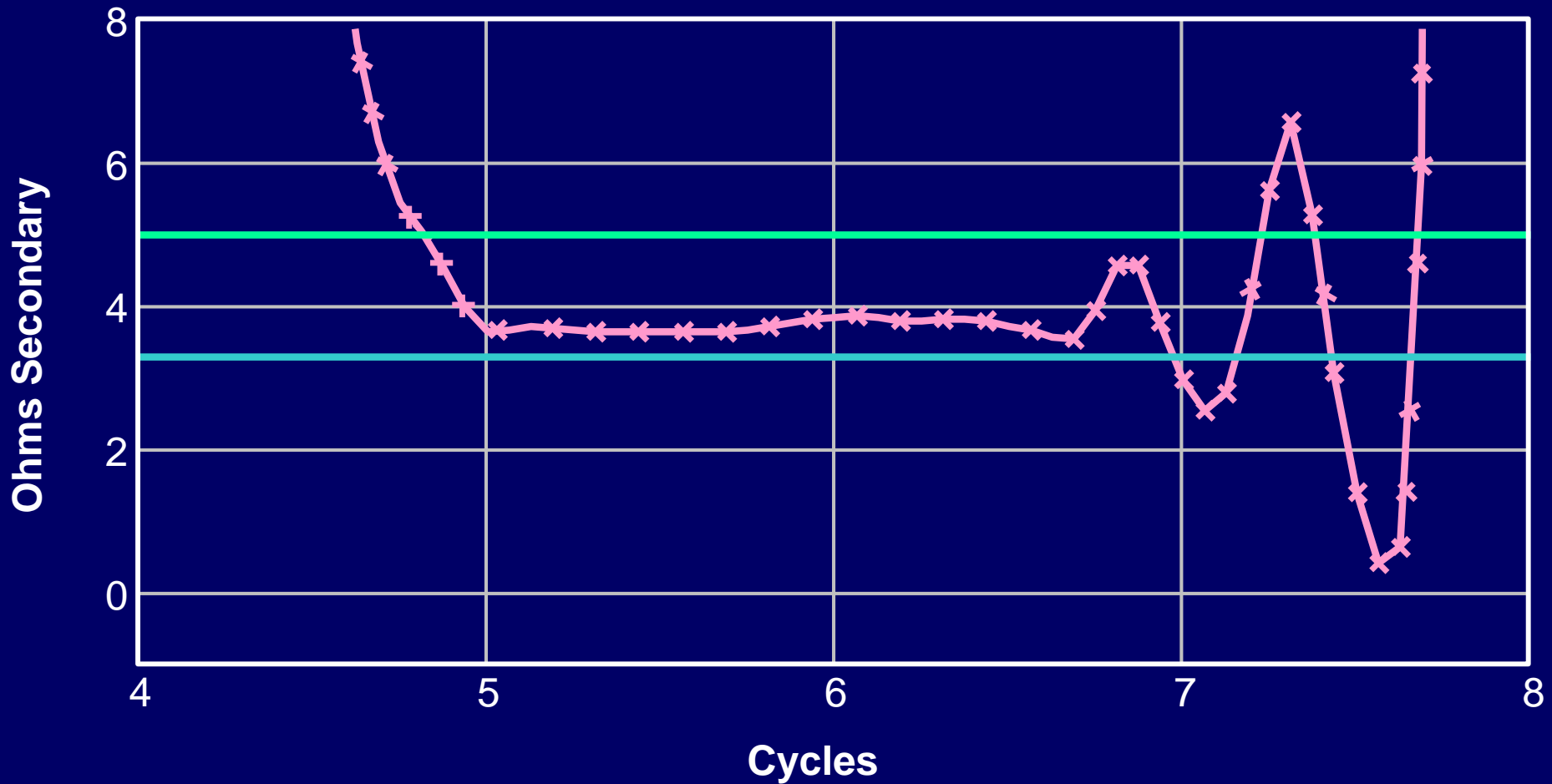
Distance Element

- Phase angle comparator
- Line-drop compensated voltage
- Polarizing voltage

Mho Element Derivation



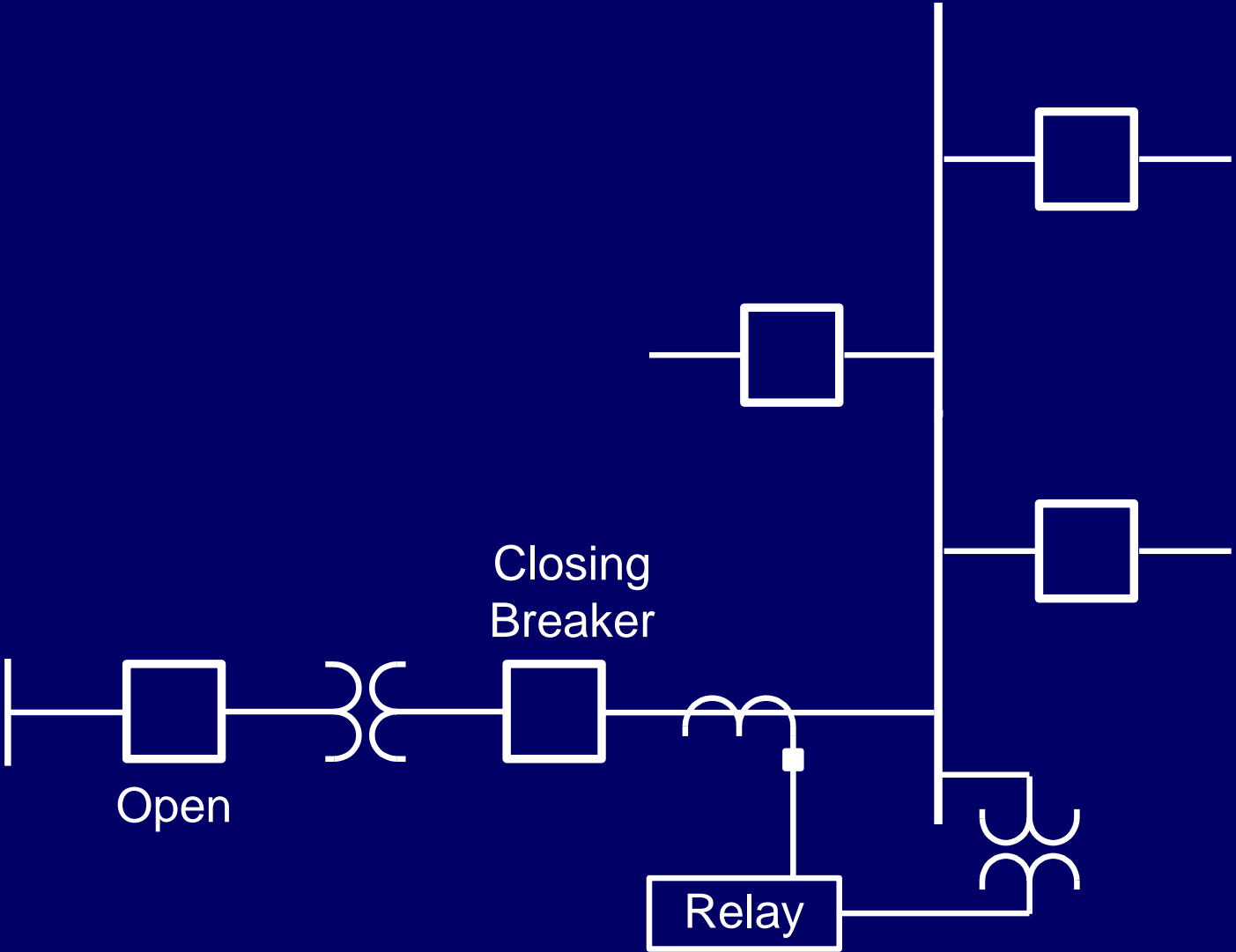
Example Impedance Plot



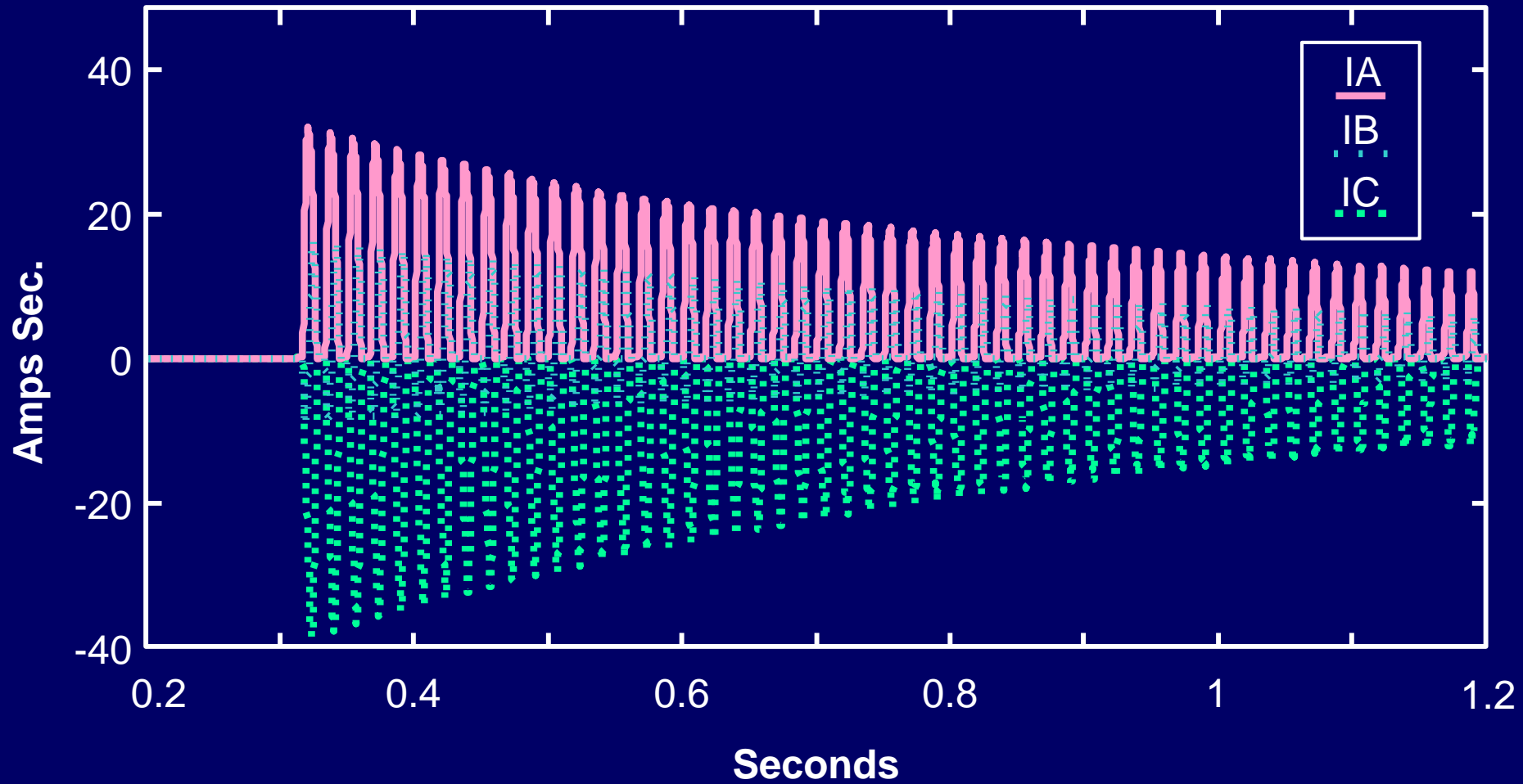
Application Examples

- Dedicated, single transformer
- Multiple tapped transformers on line
- Field event

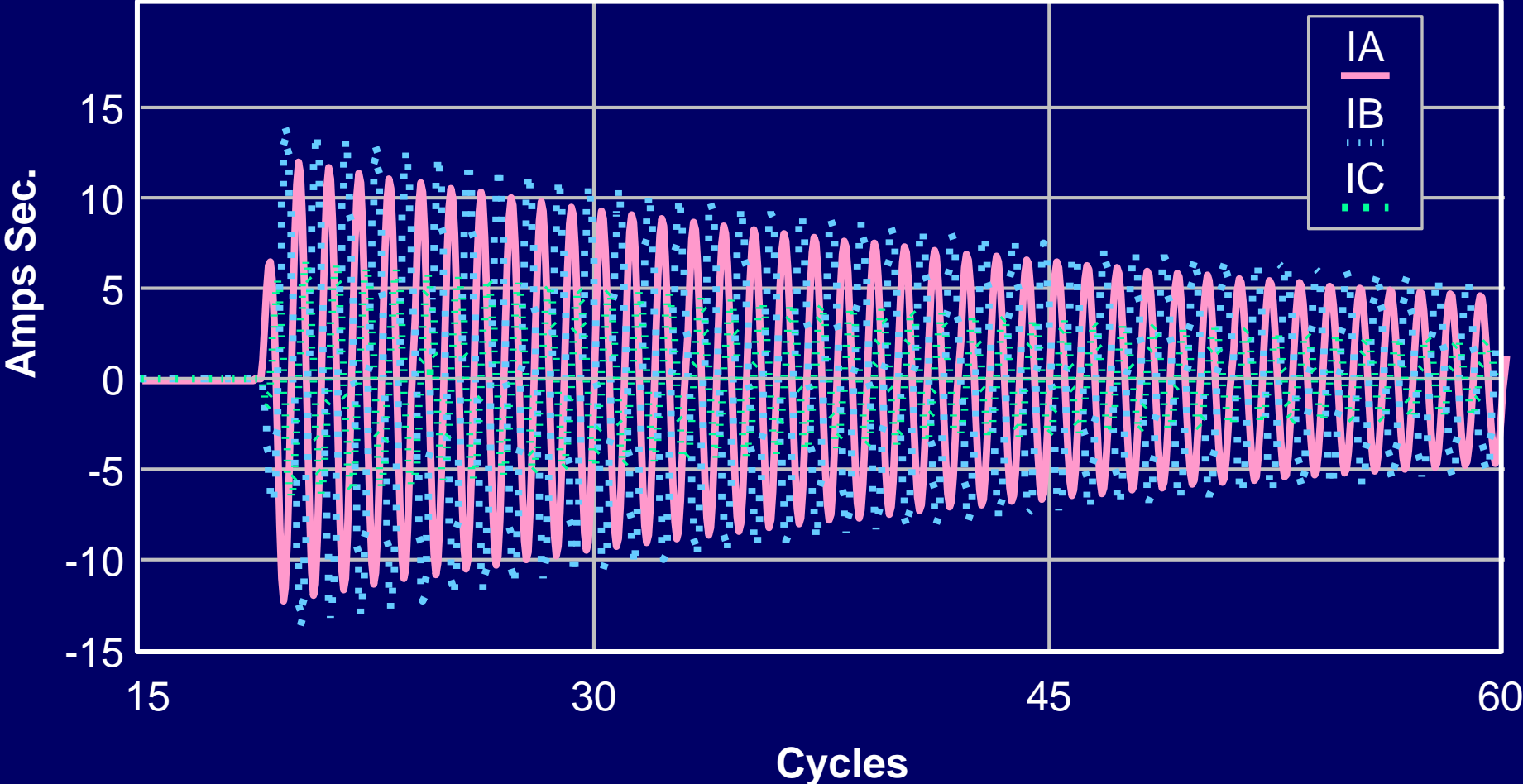
Single Transformer System Diagram



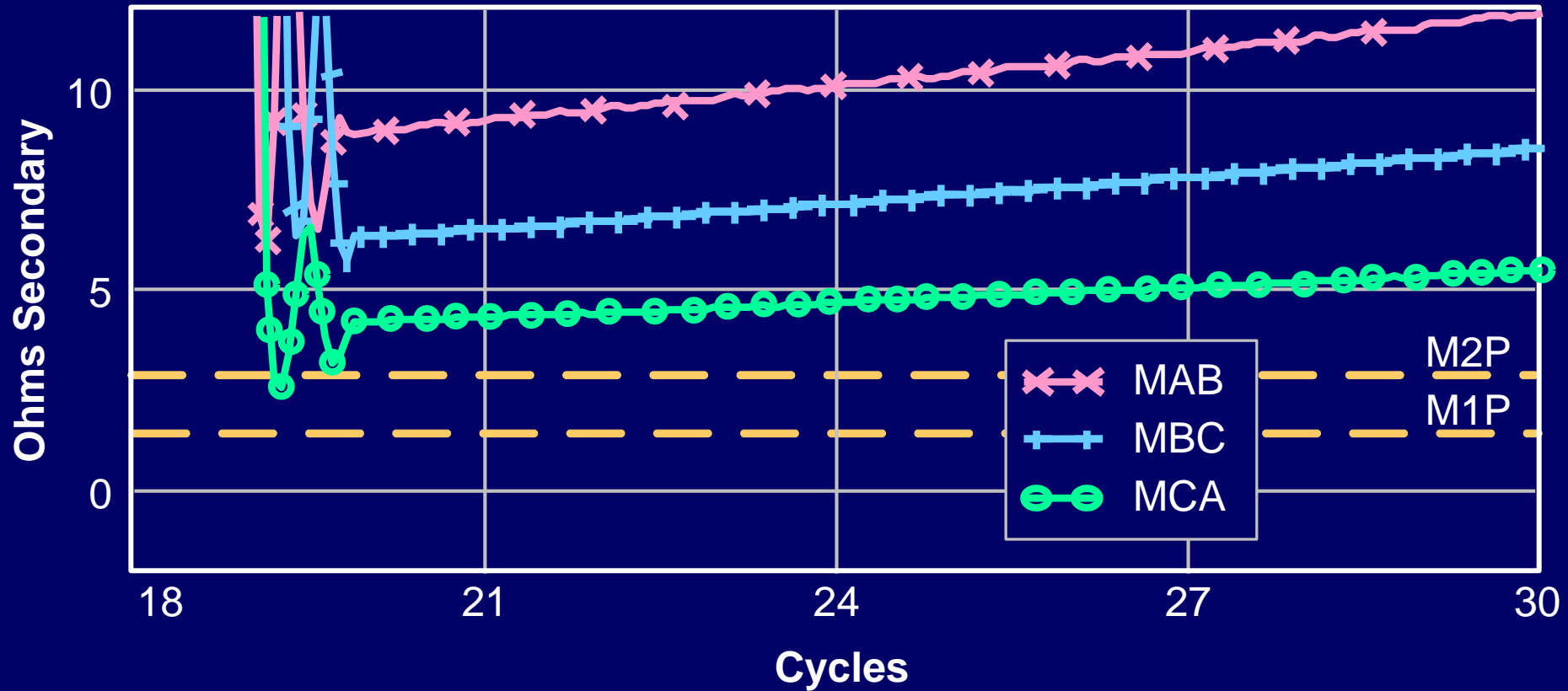
Single Transformer Inrush Currents



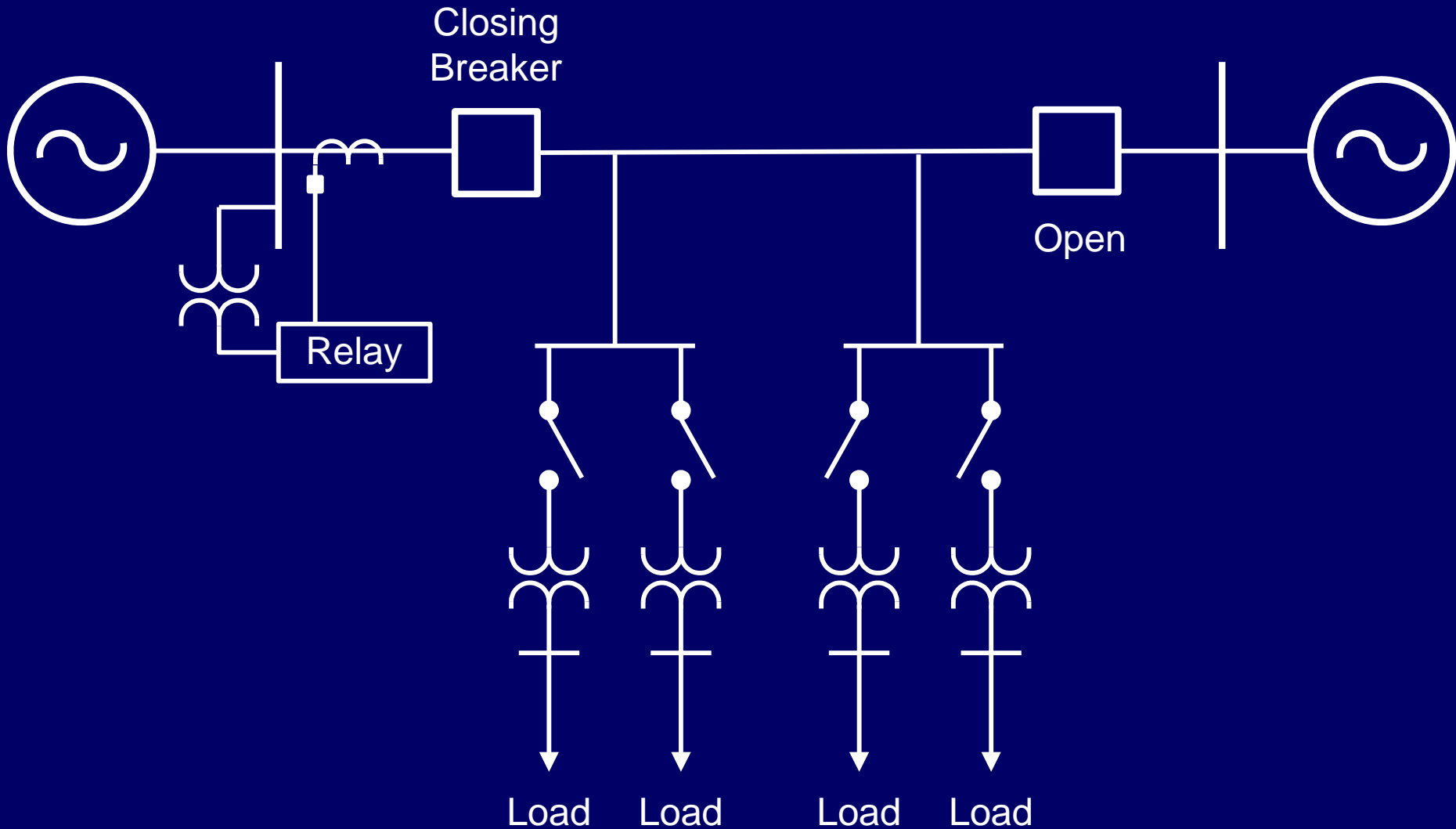
Single Transformer Filtered Inrush Currents



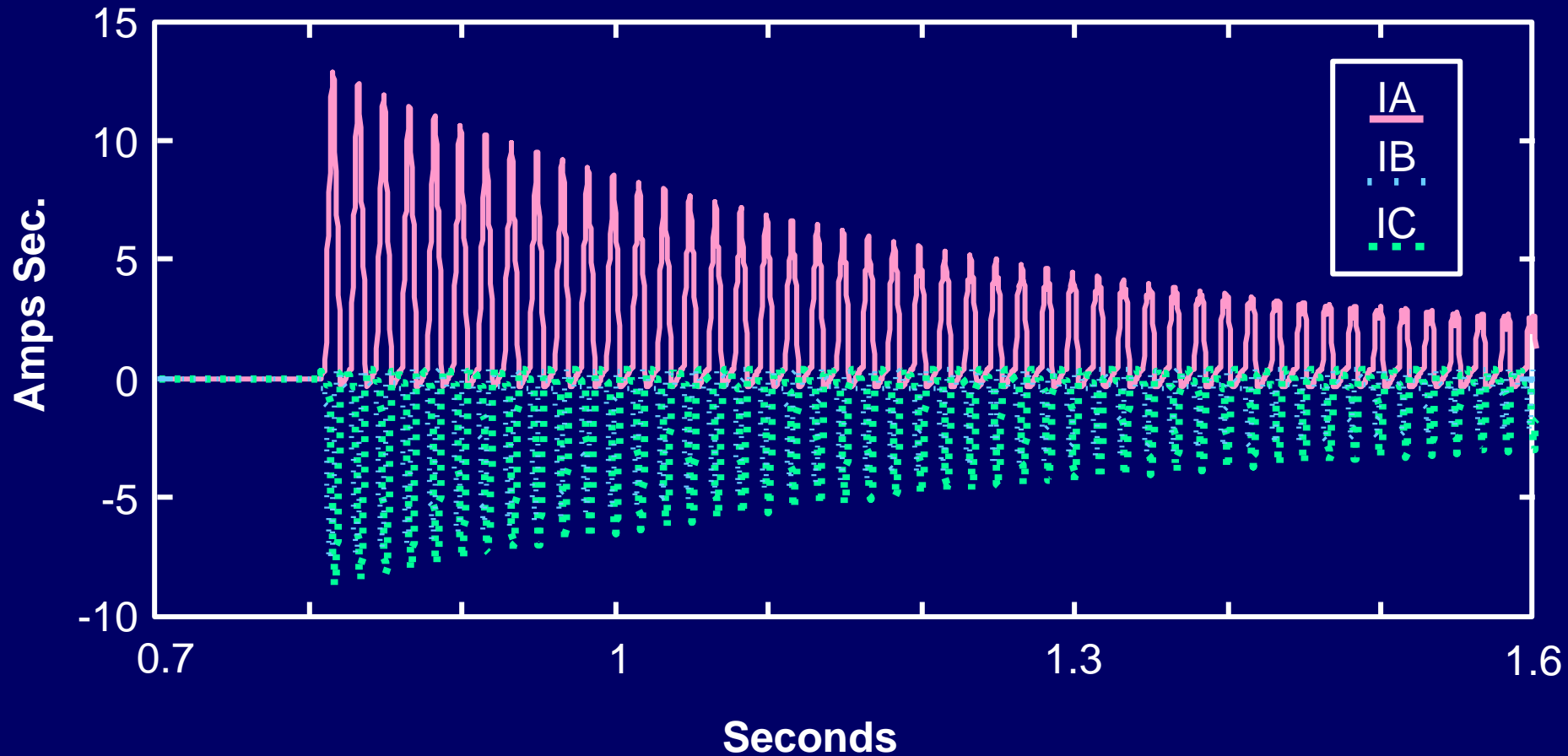
Impedance Plot for Single Transformer Inrush



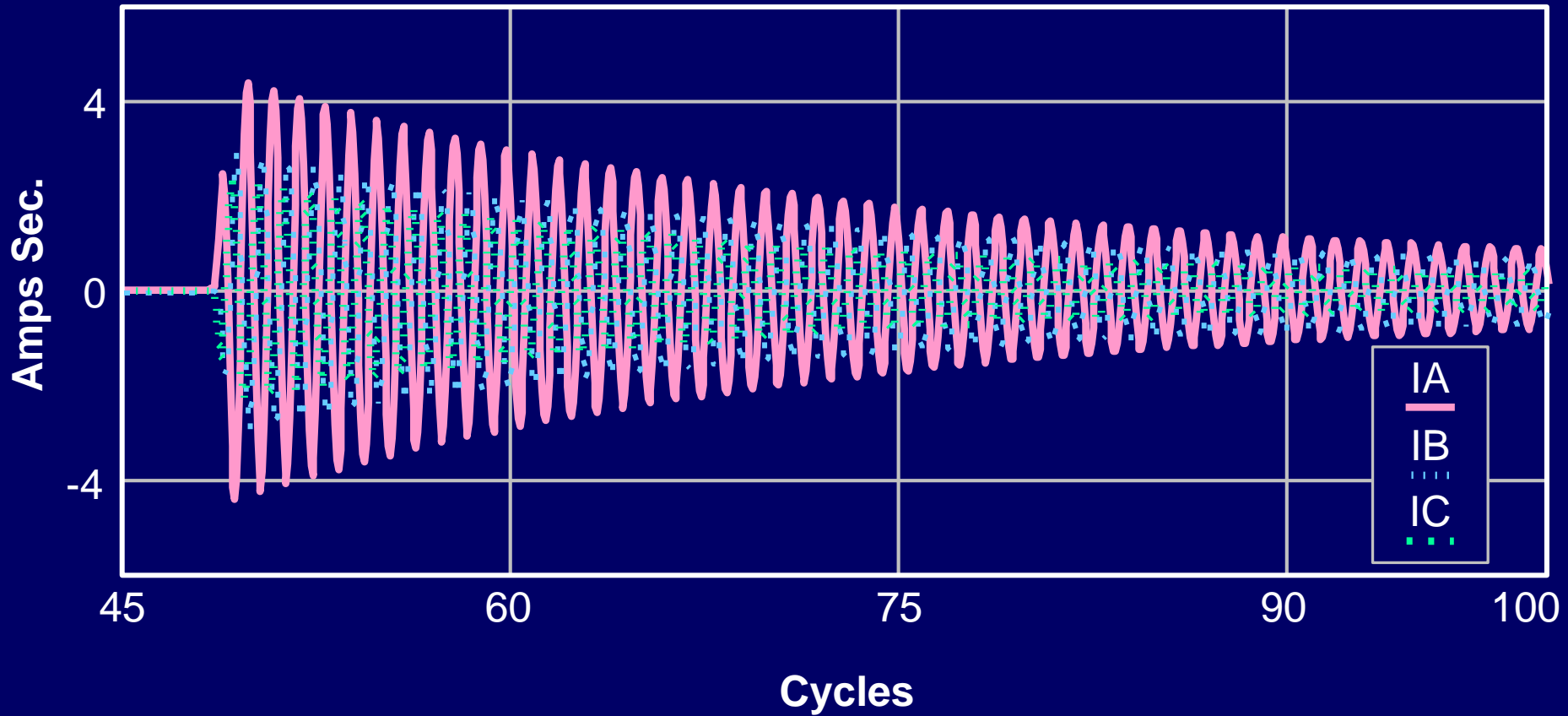
Tapped Transformer System Diagram



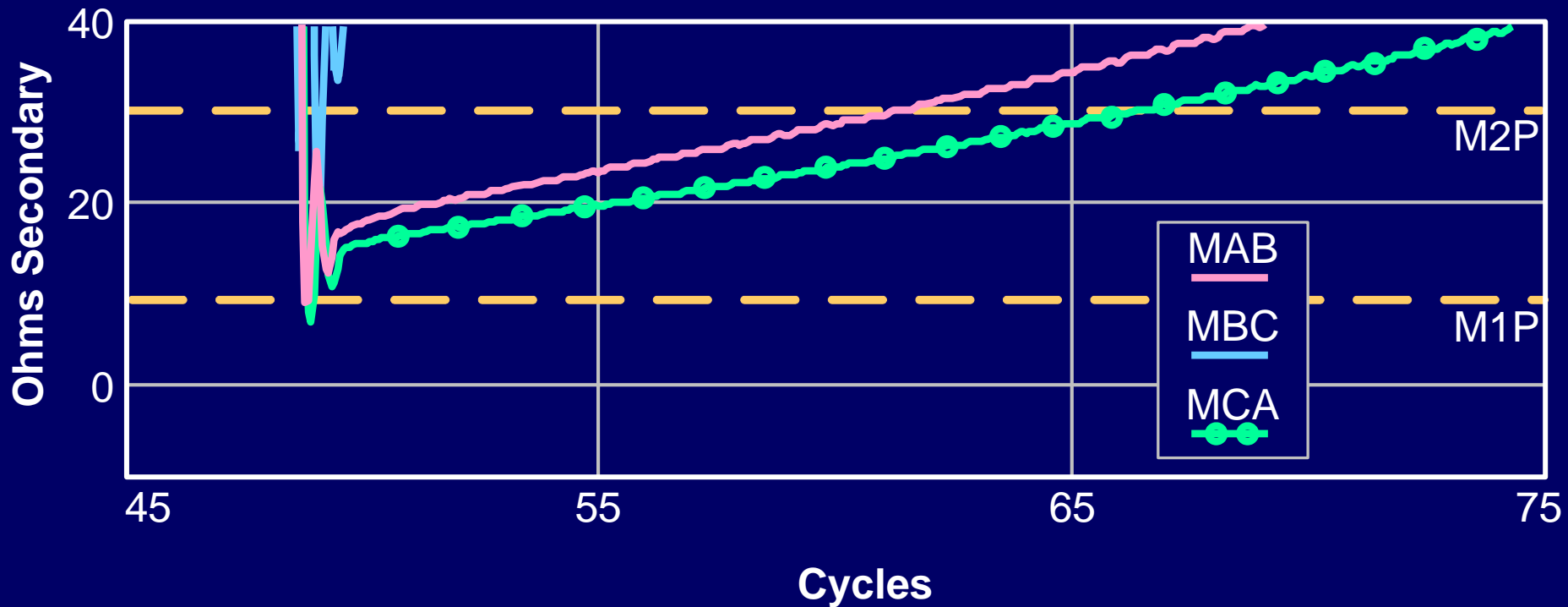
Tapped Transformer Inrush Currents



Tapped Transformer Filtered Inrush Currents



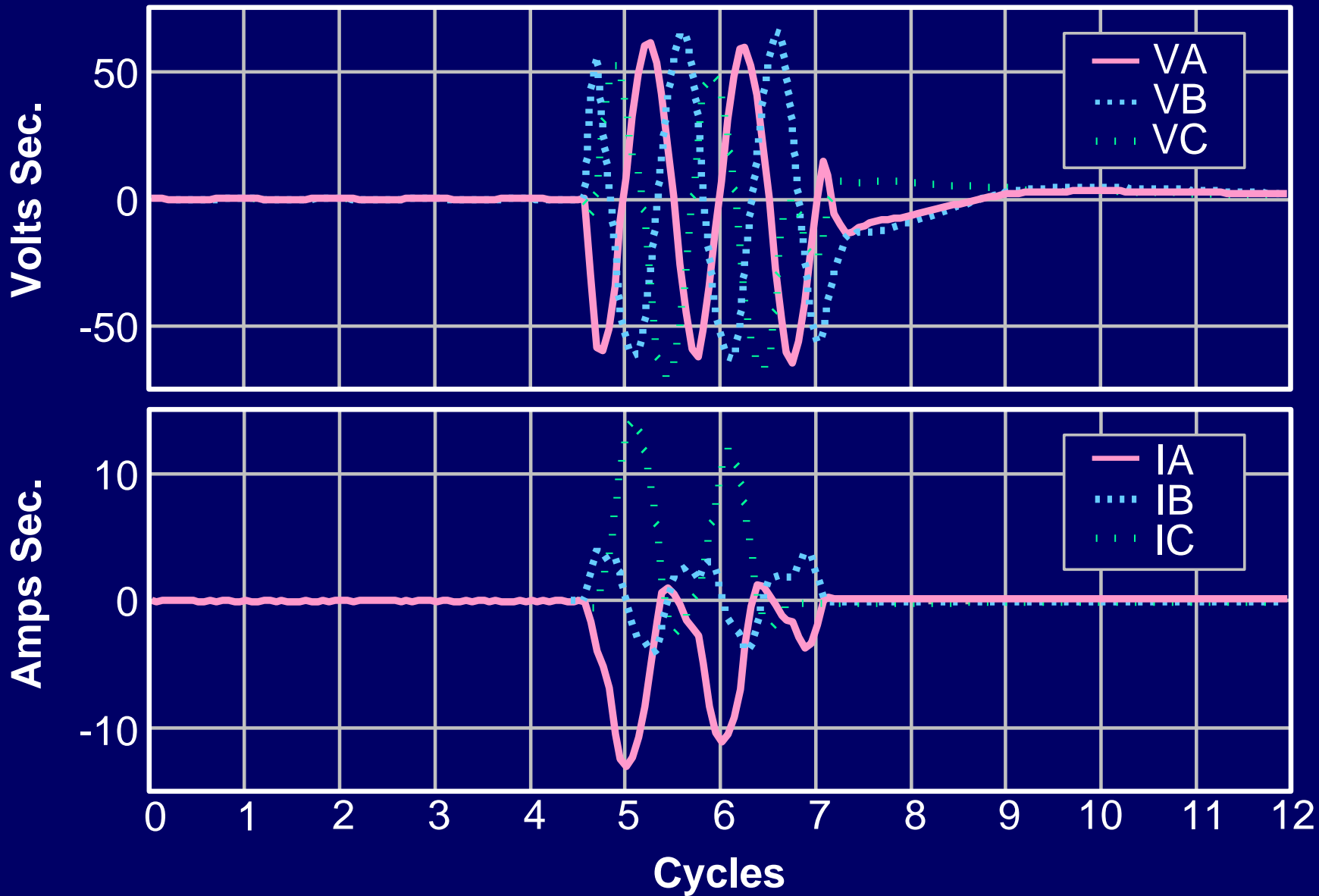
Impedance Plot for Tapped Transformer Inrush



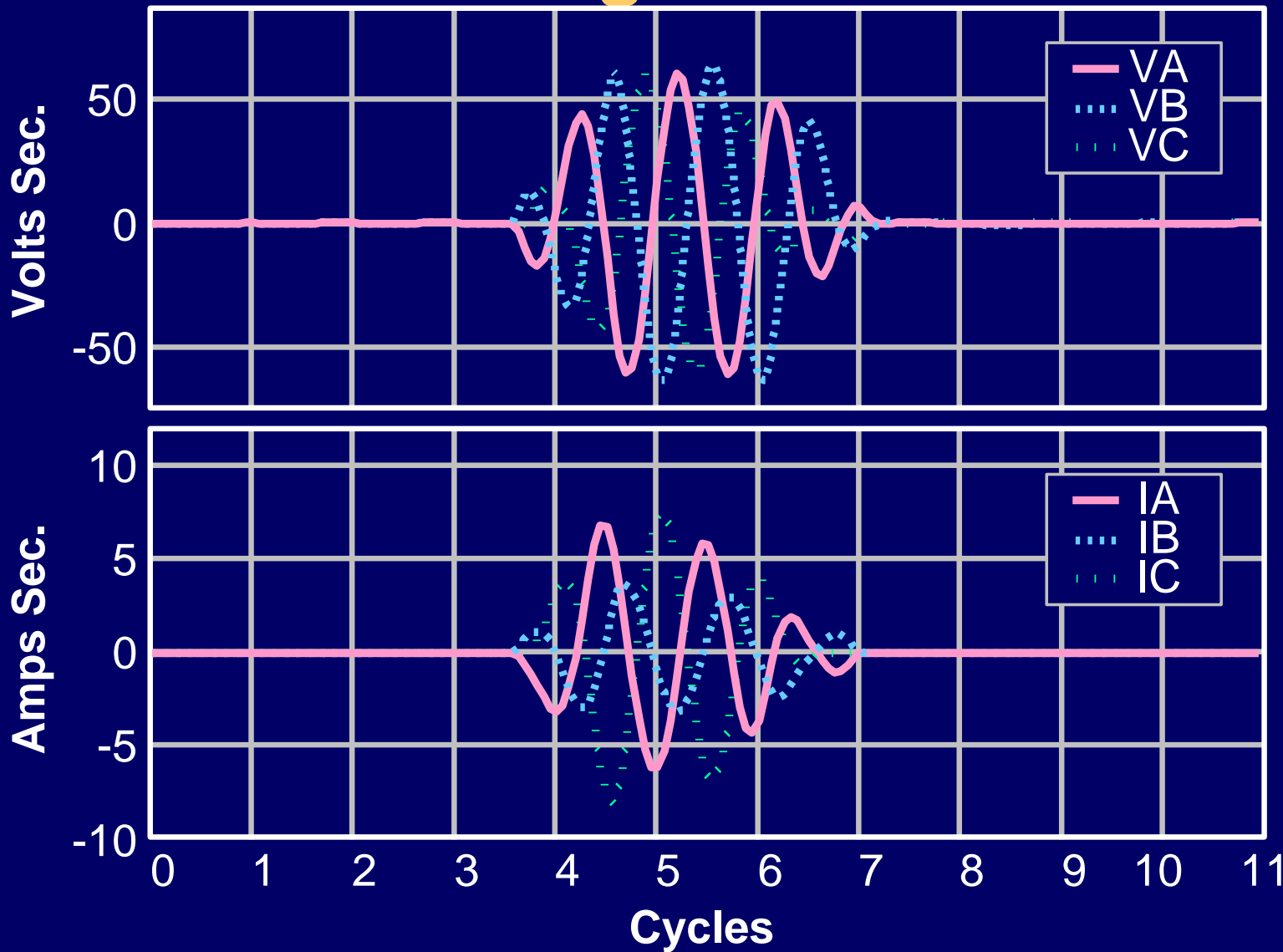
Field Event

- 138 kV line – 32 miles
- 5 – 55 MVA transformers
- Failed to energize line on three attempts
- Operation of Zone 2 distance elements resulted in failure to close

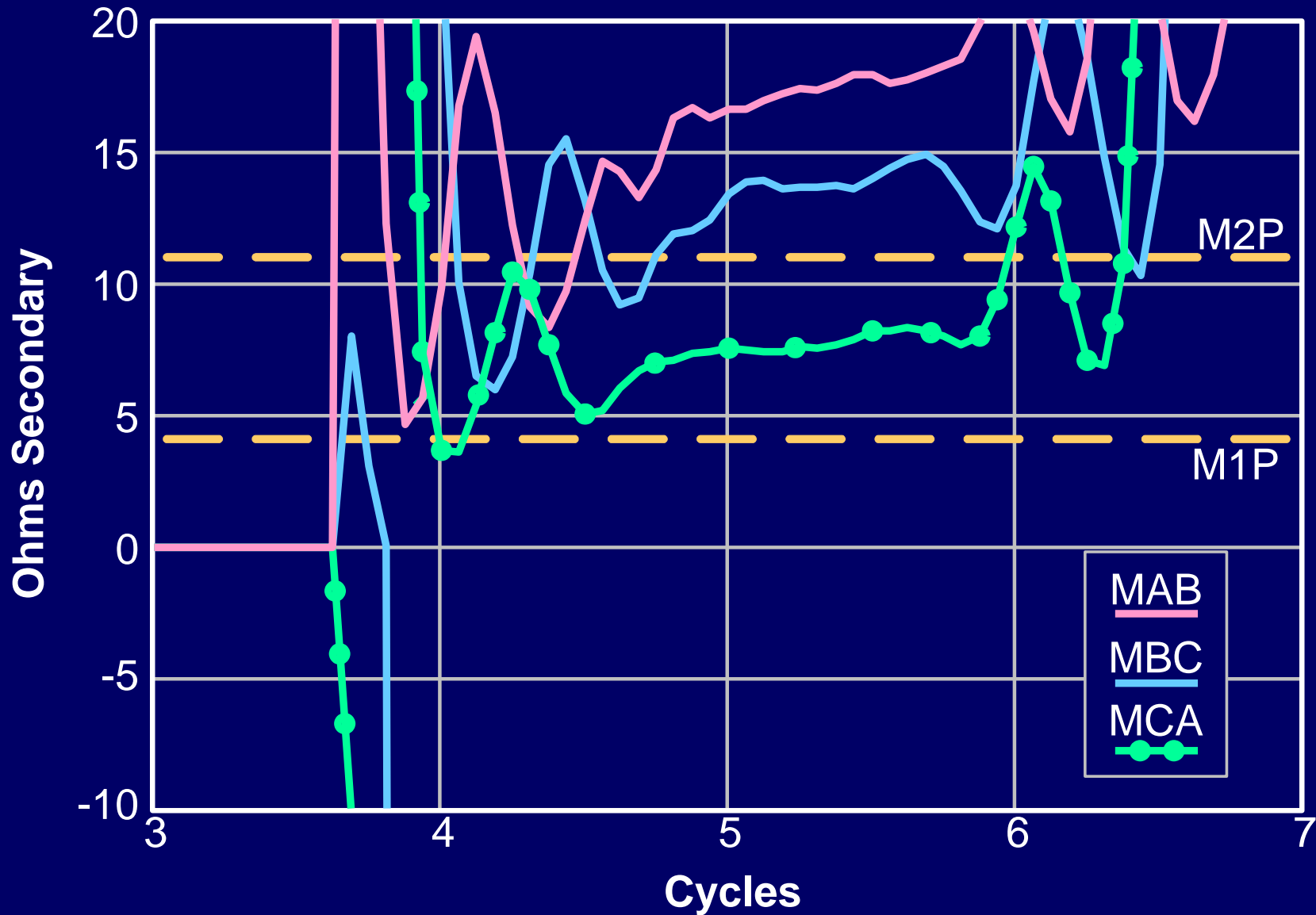
Transformer Inrush Currents



Transformer Filtered Inrush Currents After Digital Filter



Impedance Plot for Transformer Inrush



Recommendations

- Zone 1 distance elements
 - ◆ Reduce reach
 - ◆ Overcurrent fault detectors
- Overreaching distance elements
 - ◆ Time-delayed backup; delay is typically long enough to avoid operation
 - ◆ Switch-onto-fault; use voltage supervision
 - ◆ Evaluate reach based upon maximum inrush

Conclusion

- Digital relay filtering rejects harmonics and extract fundamental component
- Transformer inrush is high in harmonics and fundamental component
- Distance relay can operate on inrush currents
- Appropriate settings can avoid undesired operation