Distance Element Performance Under Conditions of CT Saturation

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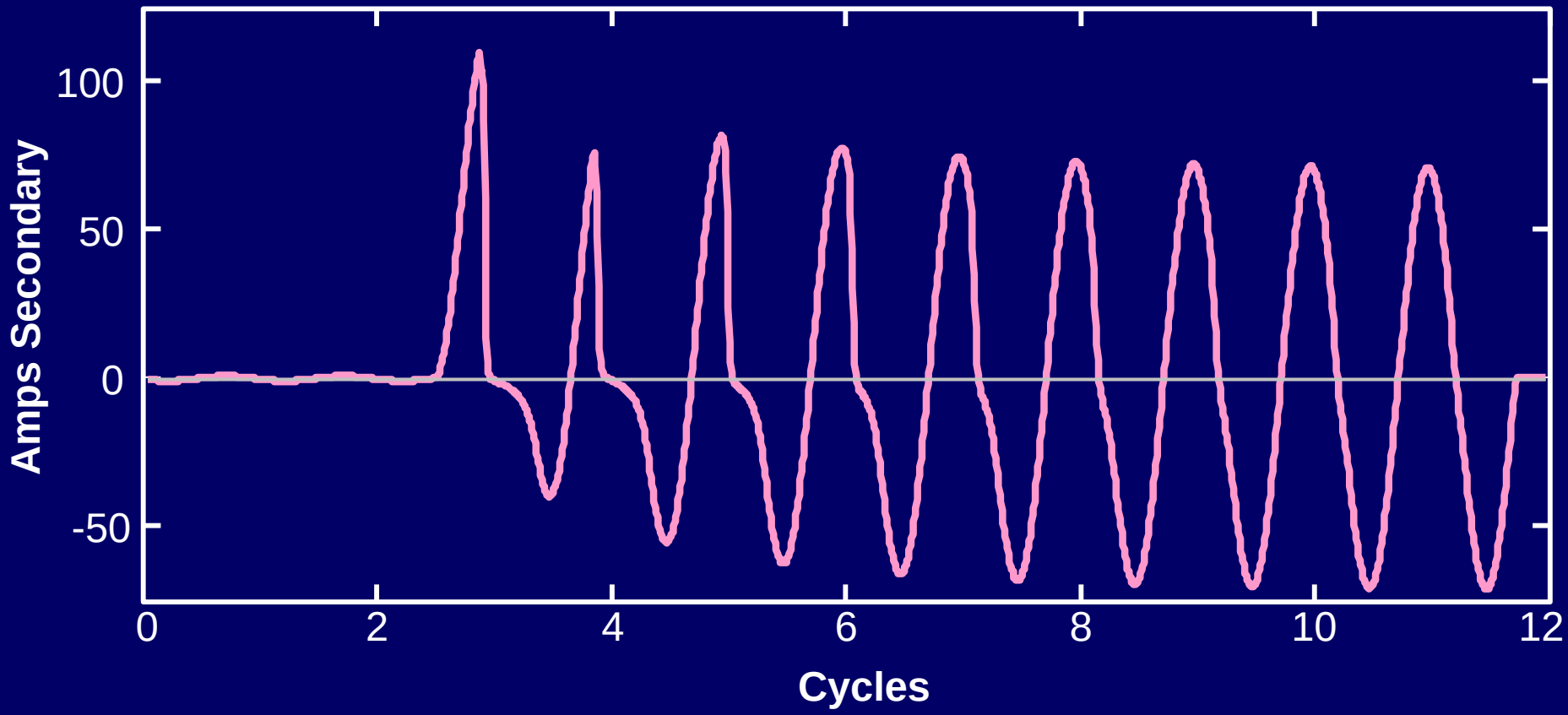
CT Saturation and Burden

- CT saturation causes waveform distortion
- CT should be sized to avoid saturation
- Maximum burden can be determined from CT and power system information

Typical CT Saturation Waveform



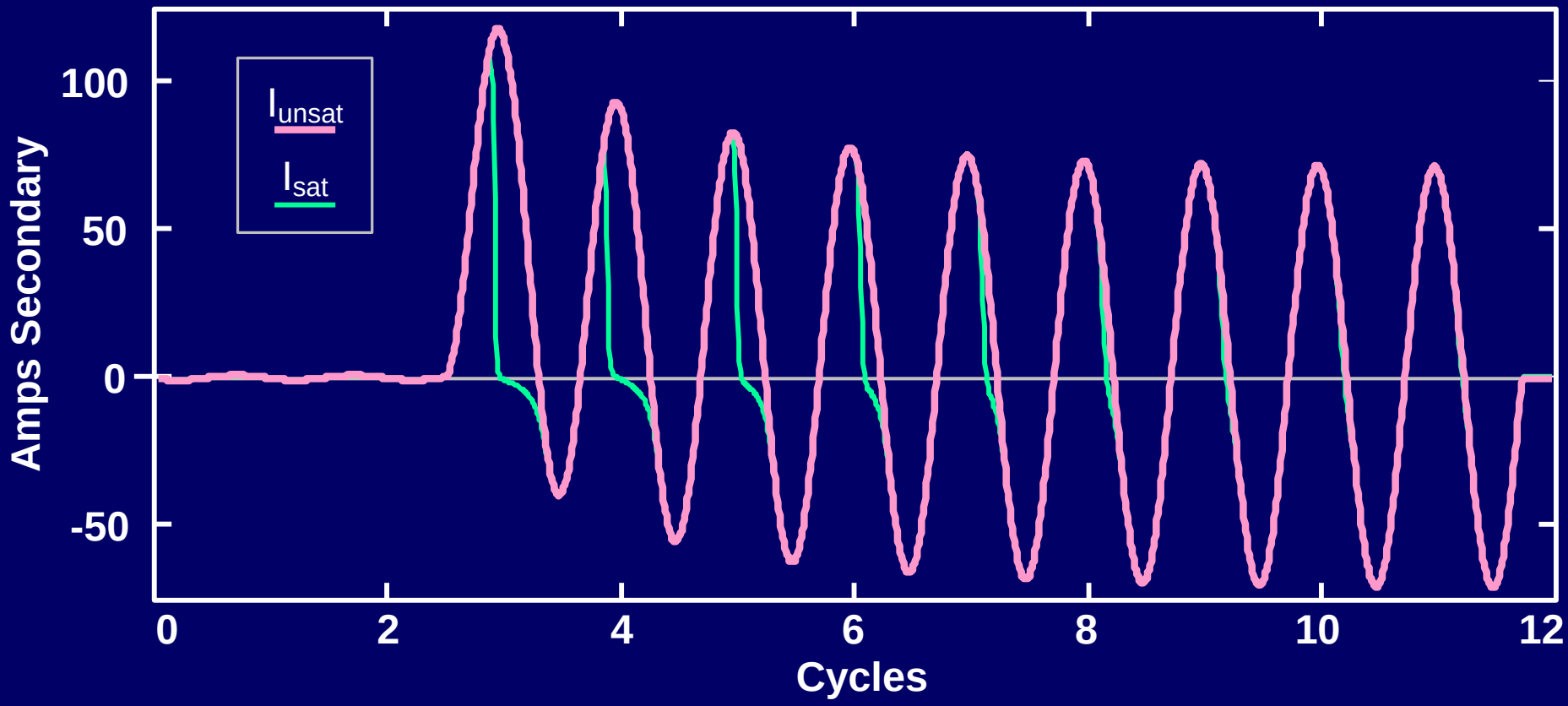
Maximum CT Burden

$$Z_{sb} \leq \frac{V_k}{\left| \frac{X}{R} + 1 \right| \cdot I_{sf}}$$

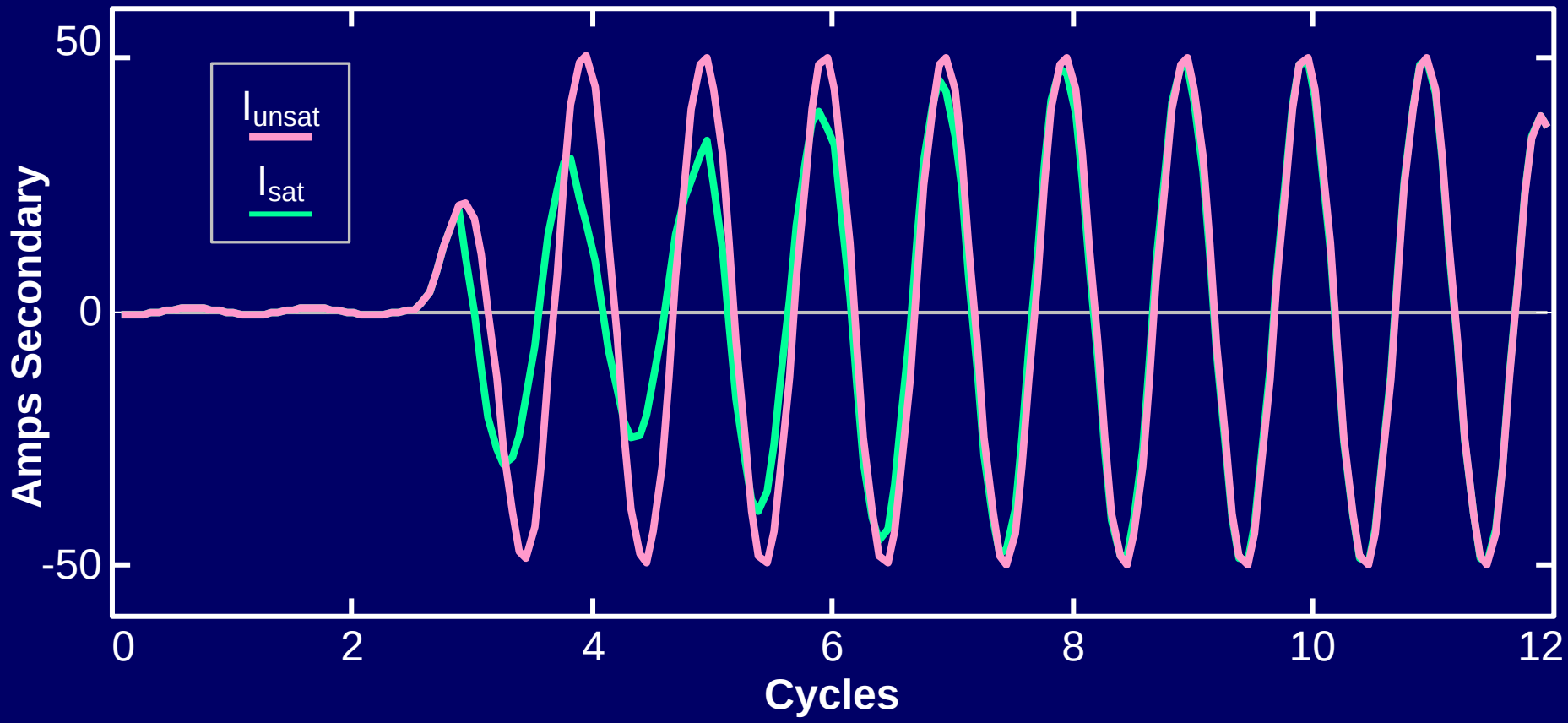
Digital Relay Filtering

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

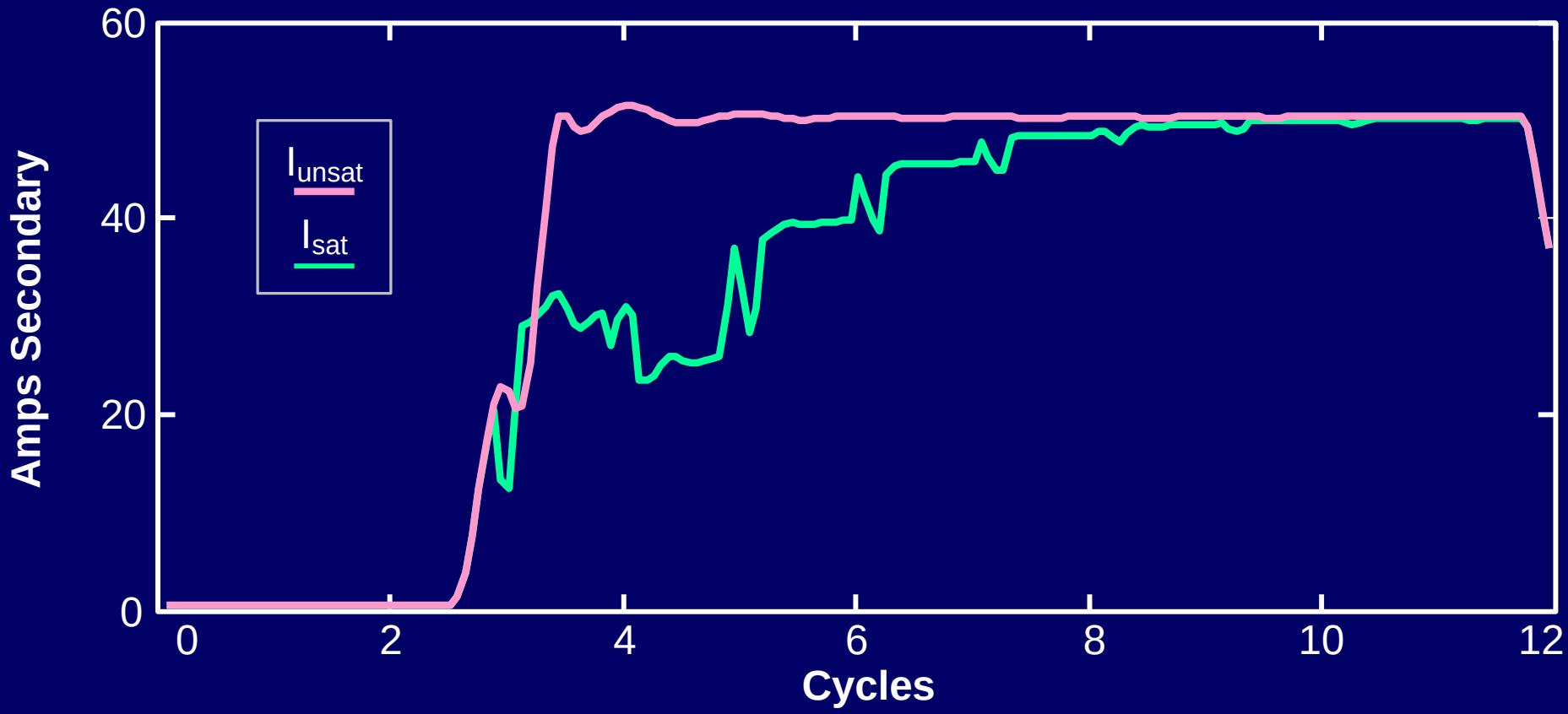
Unfiltered Current Waveforms



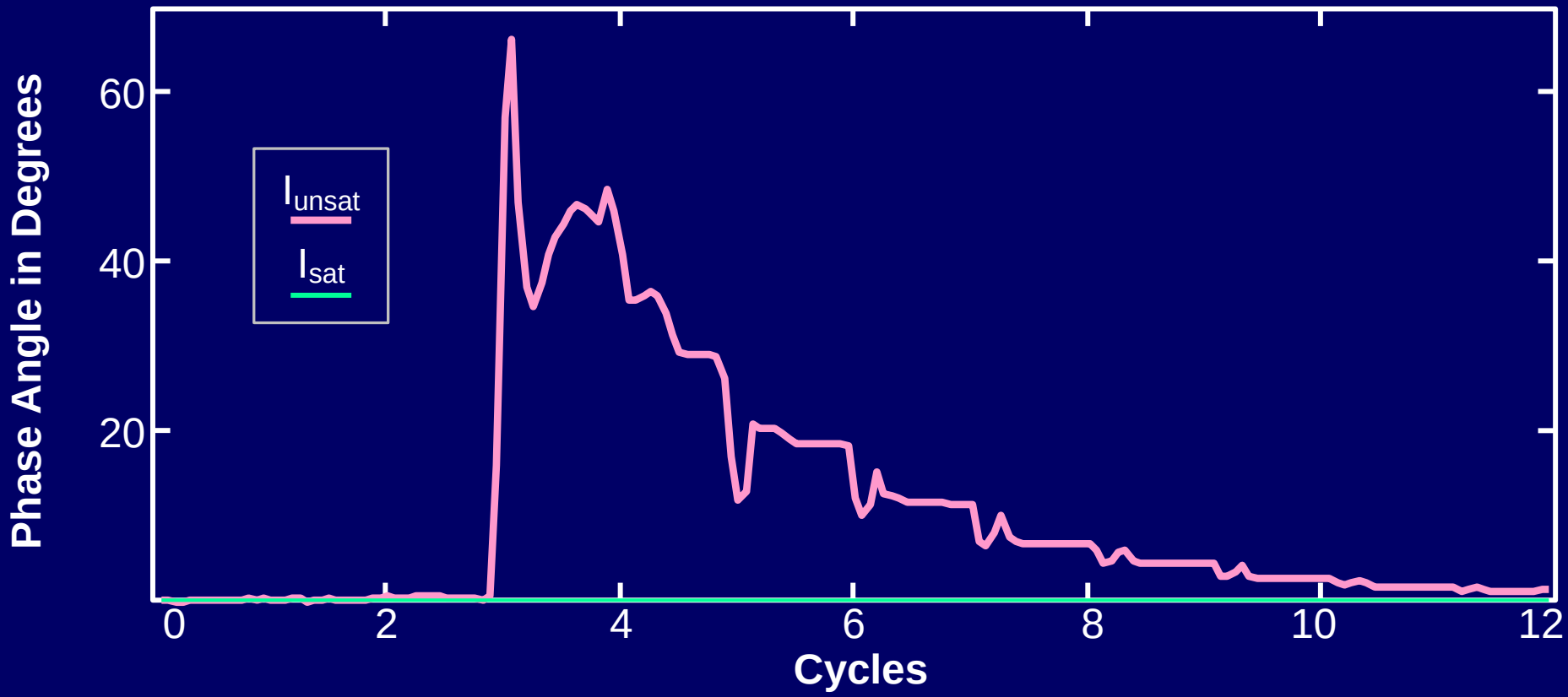
Output of Full-Cycle Cosine Filter



Current Magnitudes



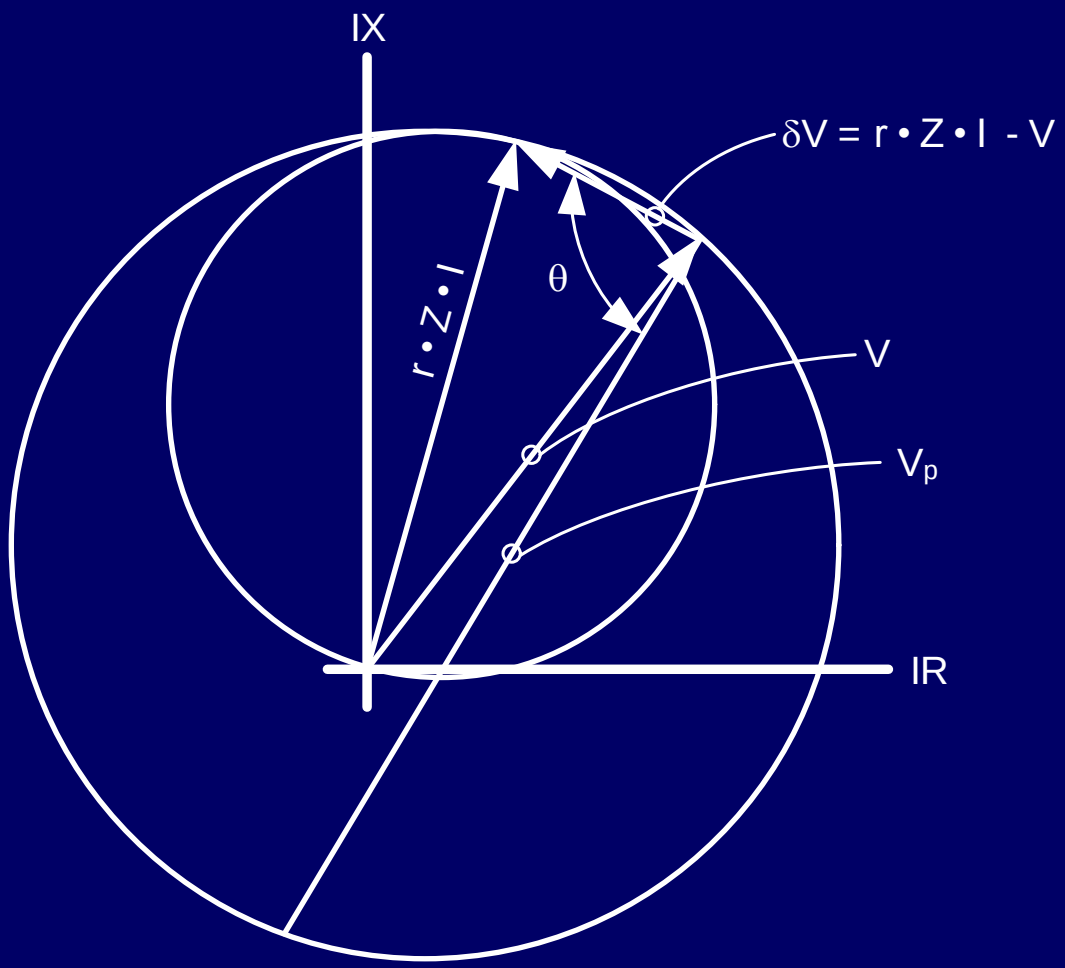
Phase Relationship of Current Waveforms



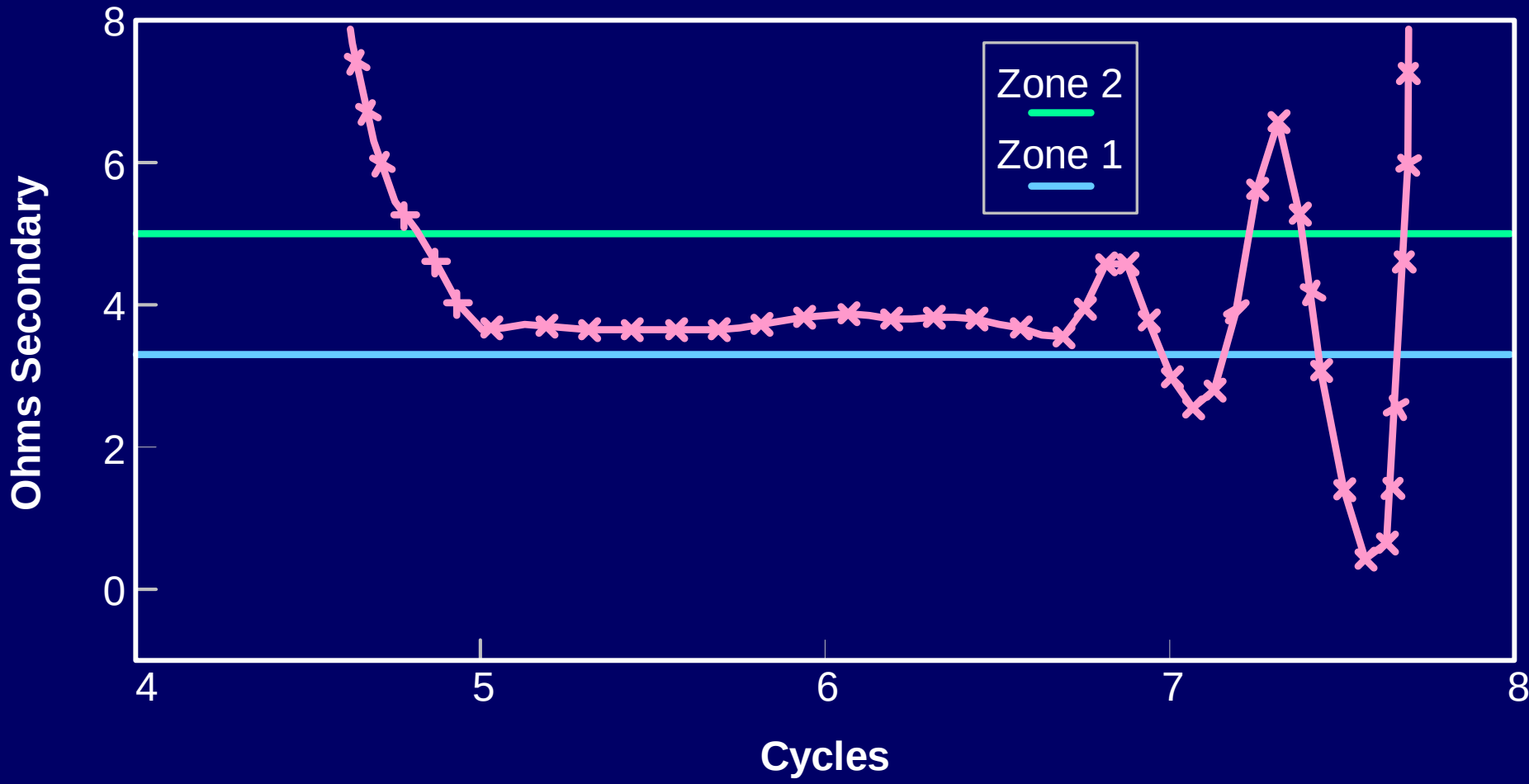
Distance Element

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

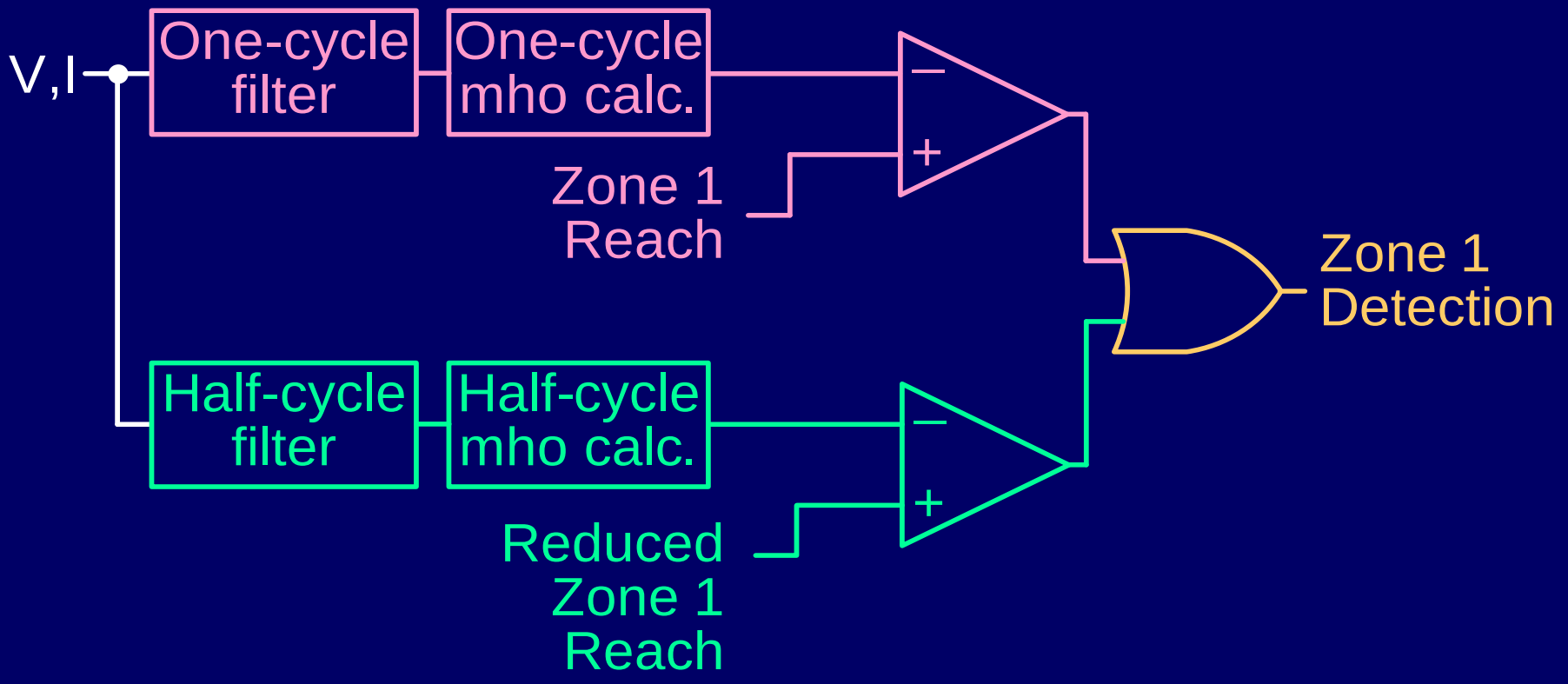
Mho Element Derivation



Example Impedance Plot



Zone 1 Distance Element Using Dual-Filter Scheme



Determine Maximum CT Burden

- 2000/5, C800, R_s = 0.76 ohms
- Maximum fault current: 35,200 amps
- System X/R: 10 (84.3 degrees)
- Maximum burden: 0.82 ohms

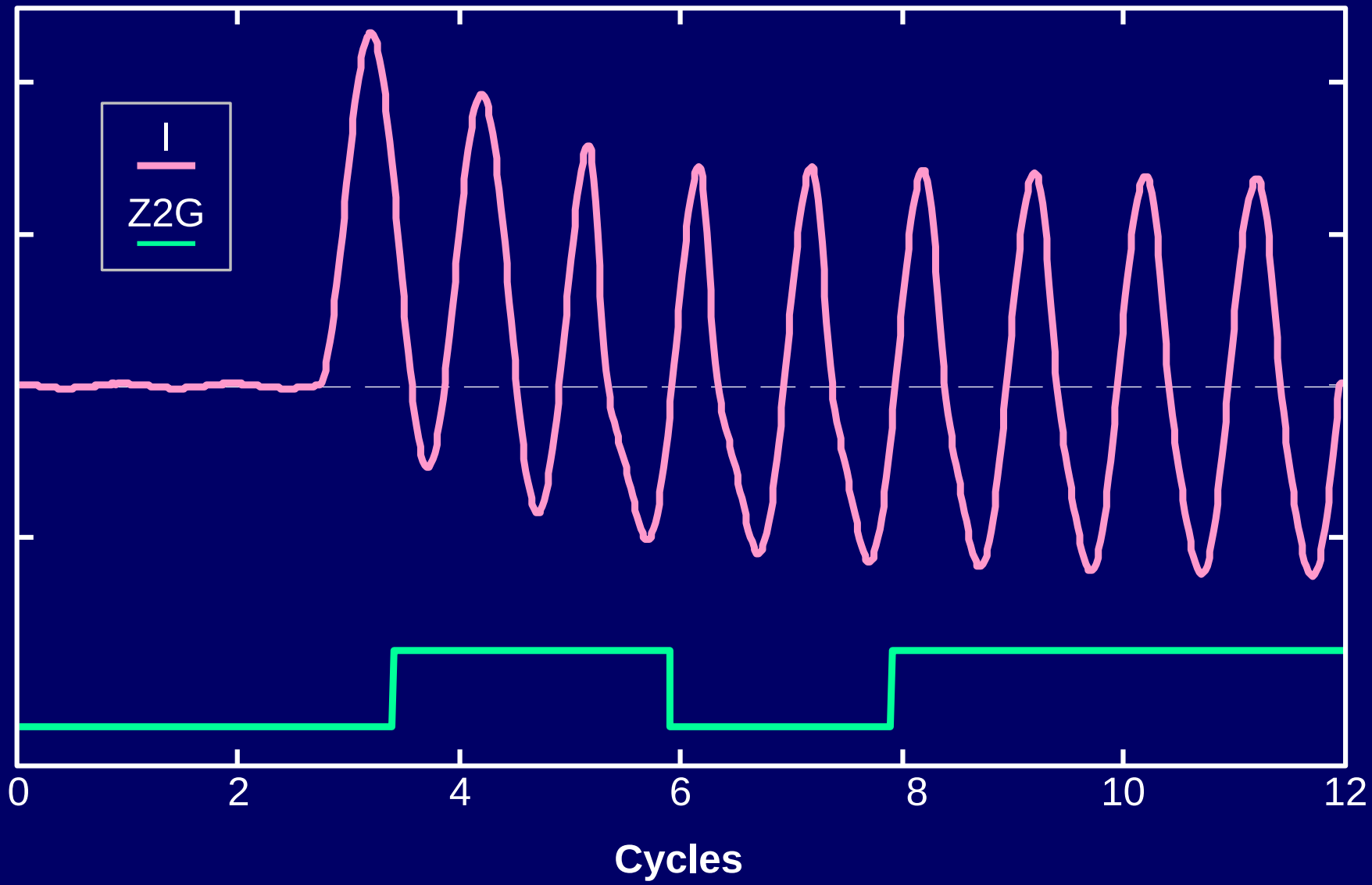
Distance Element Evaluation

- Ensure high-speed tripping by Zone 1 distance element — Close-in faults and fault at 70% of reach
- Ensure dependable operation of Zone 2 element for pilot scheme tripping
  - High-speed operation for close-in and remote terminal faults
  - Minimum pickup duration for pilot tripping

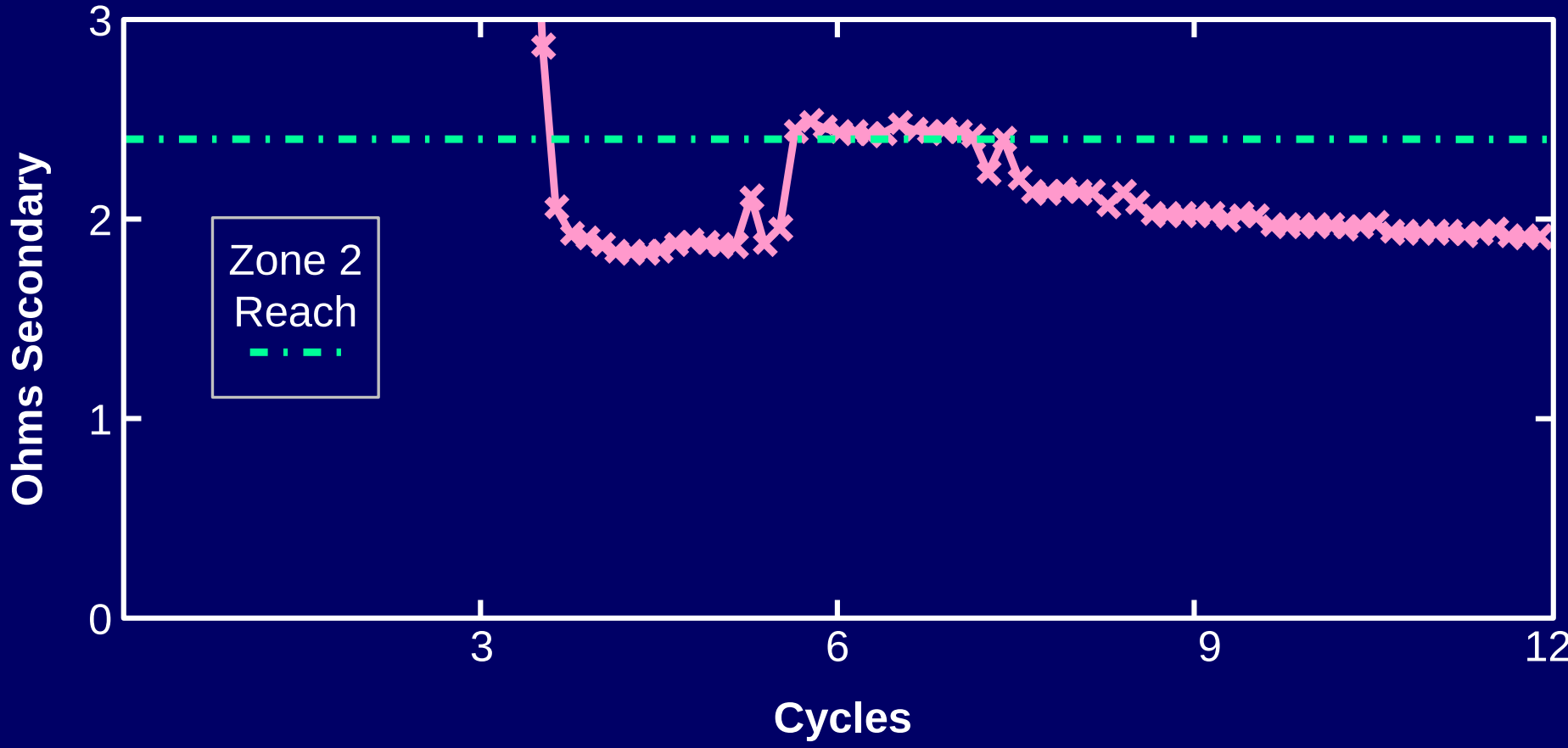
Zone 2 Operation

- Close-in fault
- Remote terminal fault
  (100% of line impedance)
- Operating time less than 0.8 cycles
- Minimum pickup duration of 2 cycles

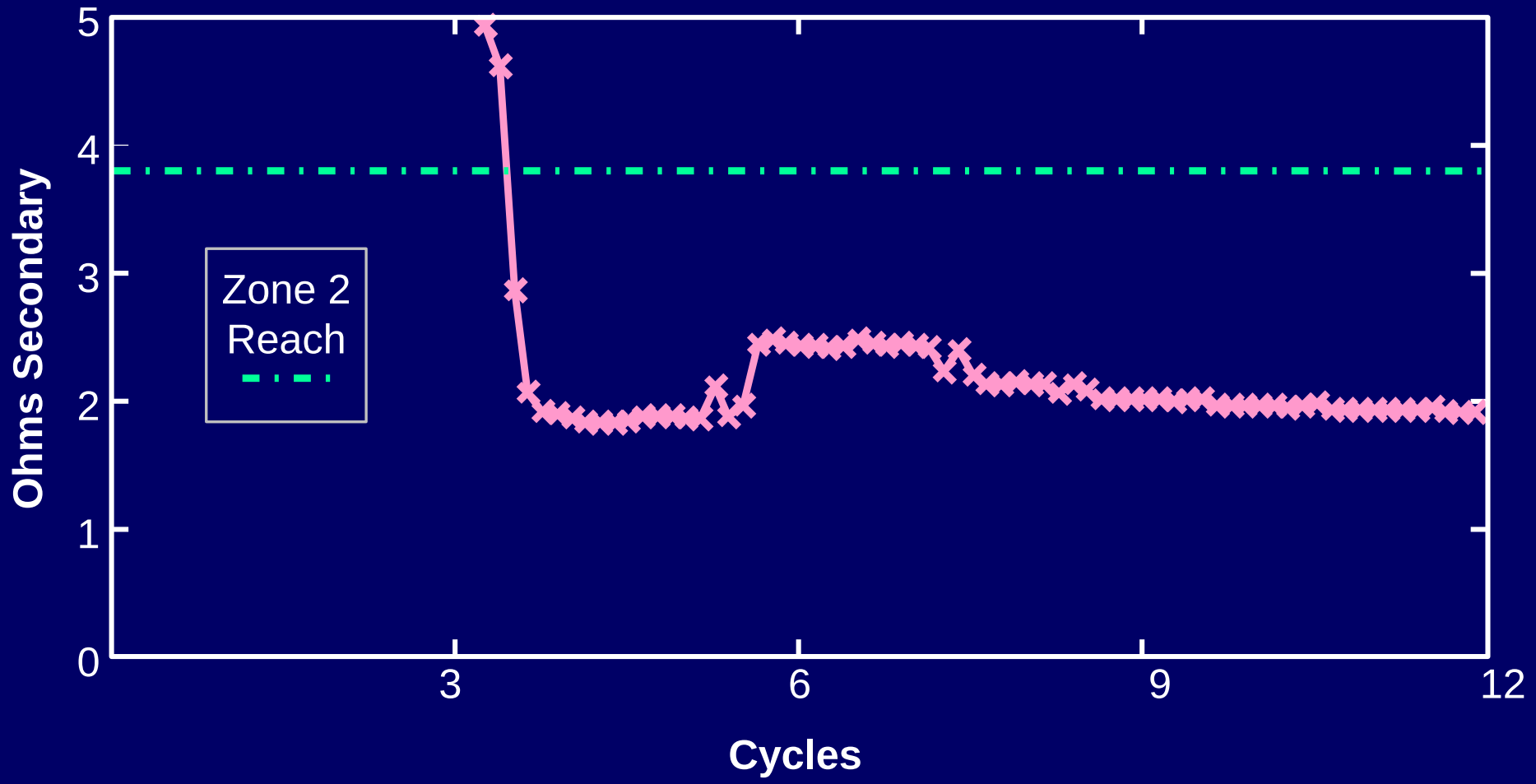
Zone 2 Distance Element Operation
Remote Fault – Six Times Maximum



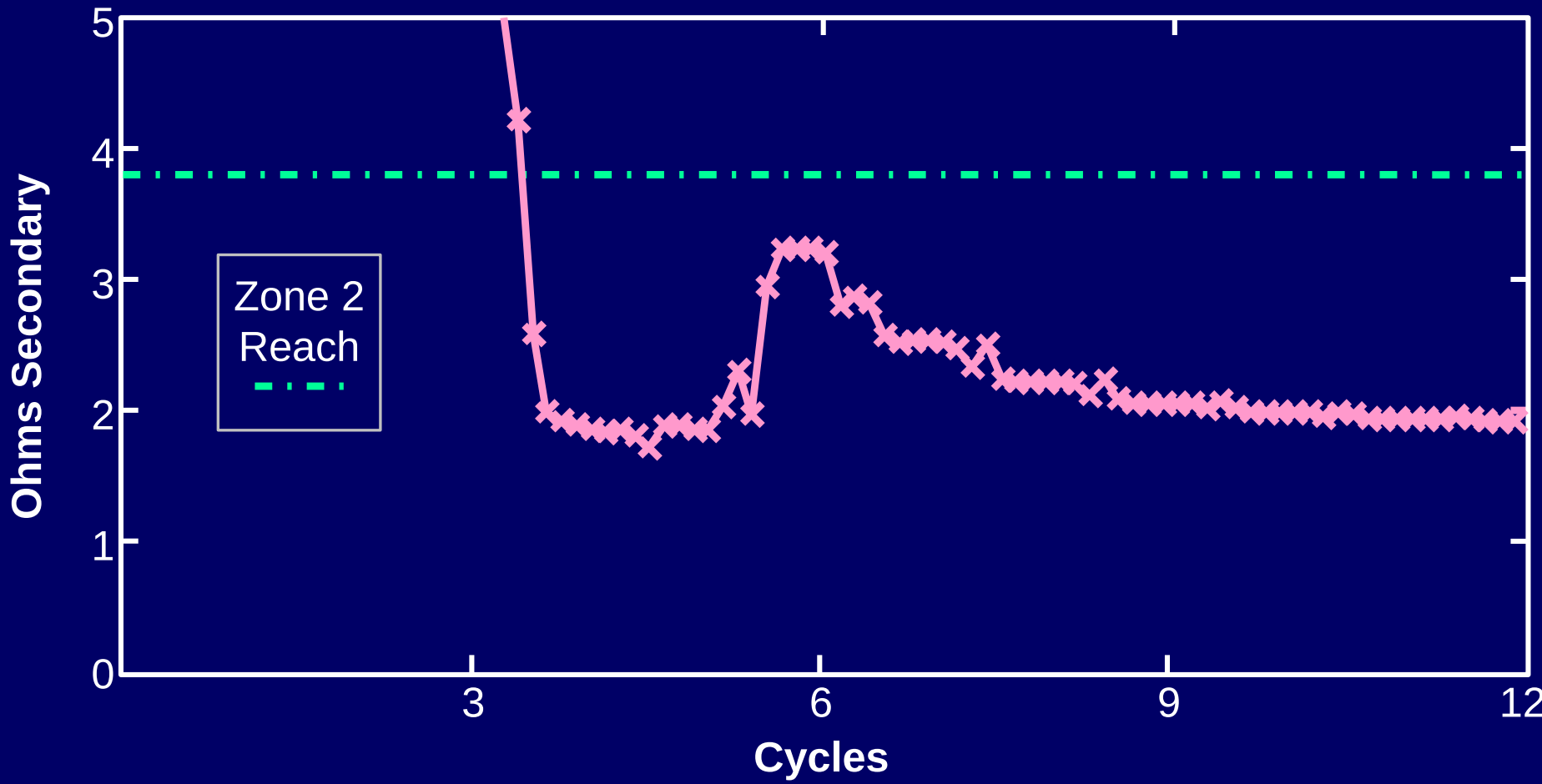
Zone 2 Mho Element Plot – Six Times Maximum



Impedance Plot With Extended Zone 2 Reach Setting



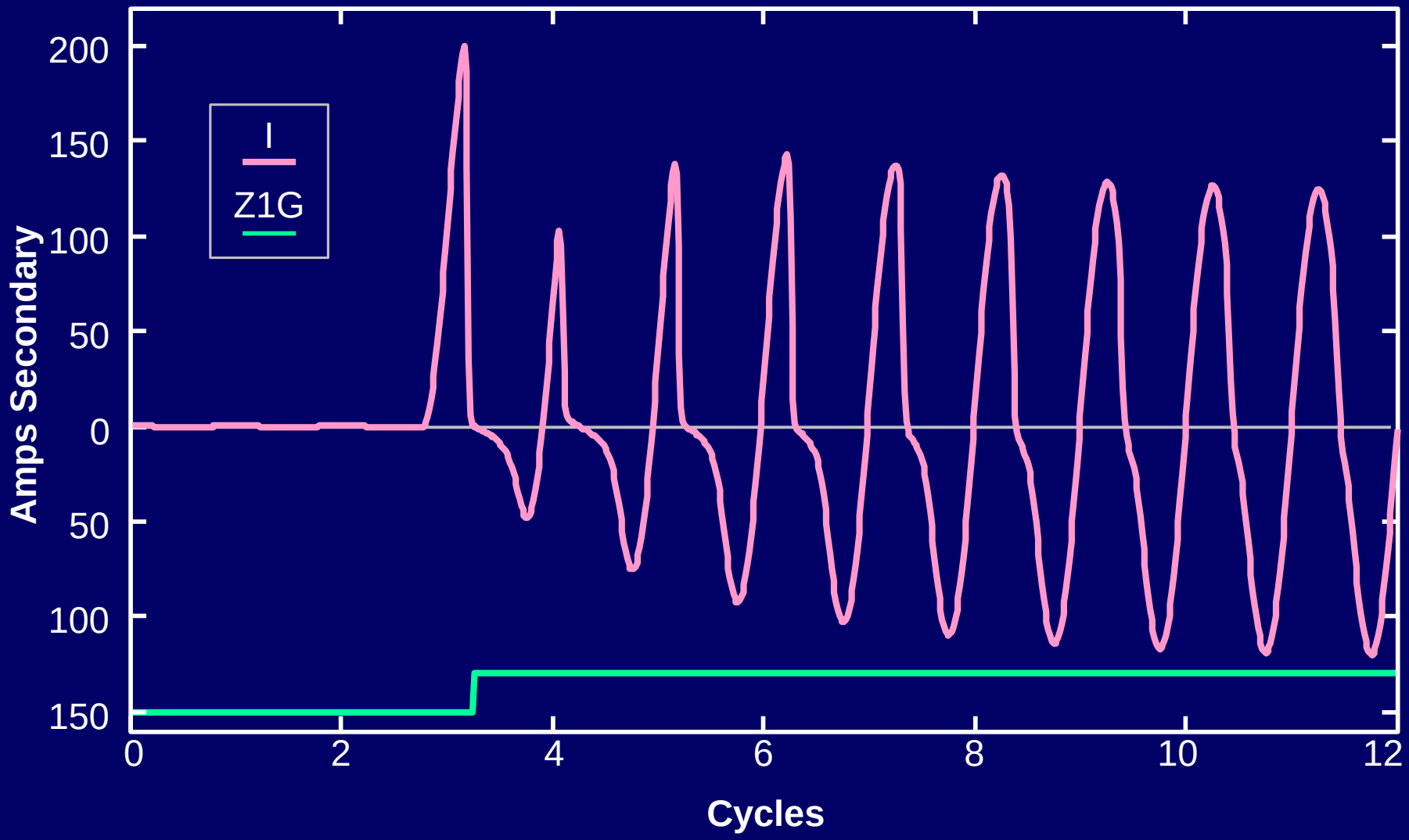
Increase CT Burden to Seven Times Maximum



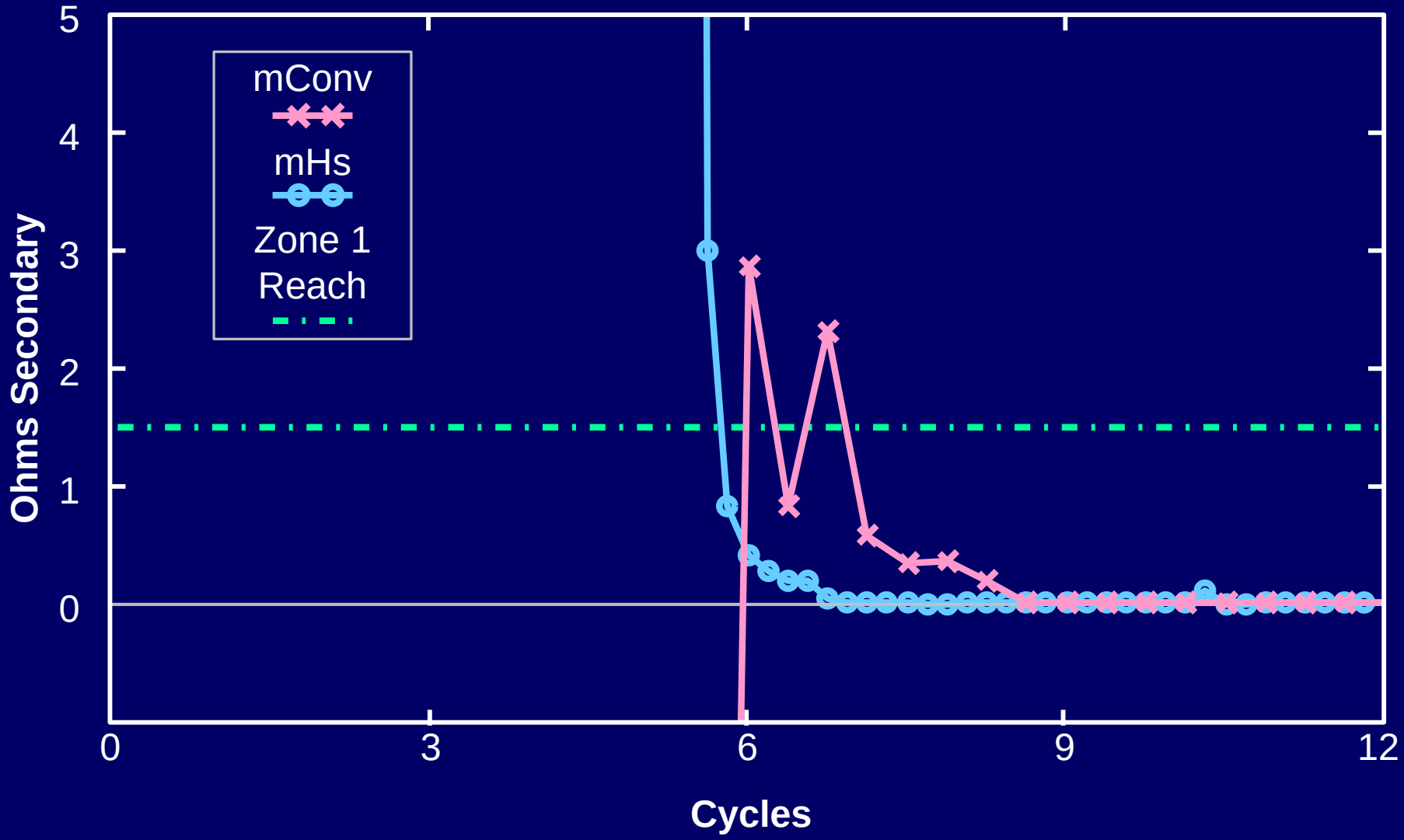
Zone 1 Operation

- Close-in fault at maximum fault current
- Fault at 70% of set reach
- Must trip within 0.8 cycles
- No duration requirement

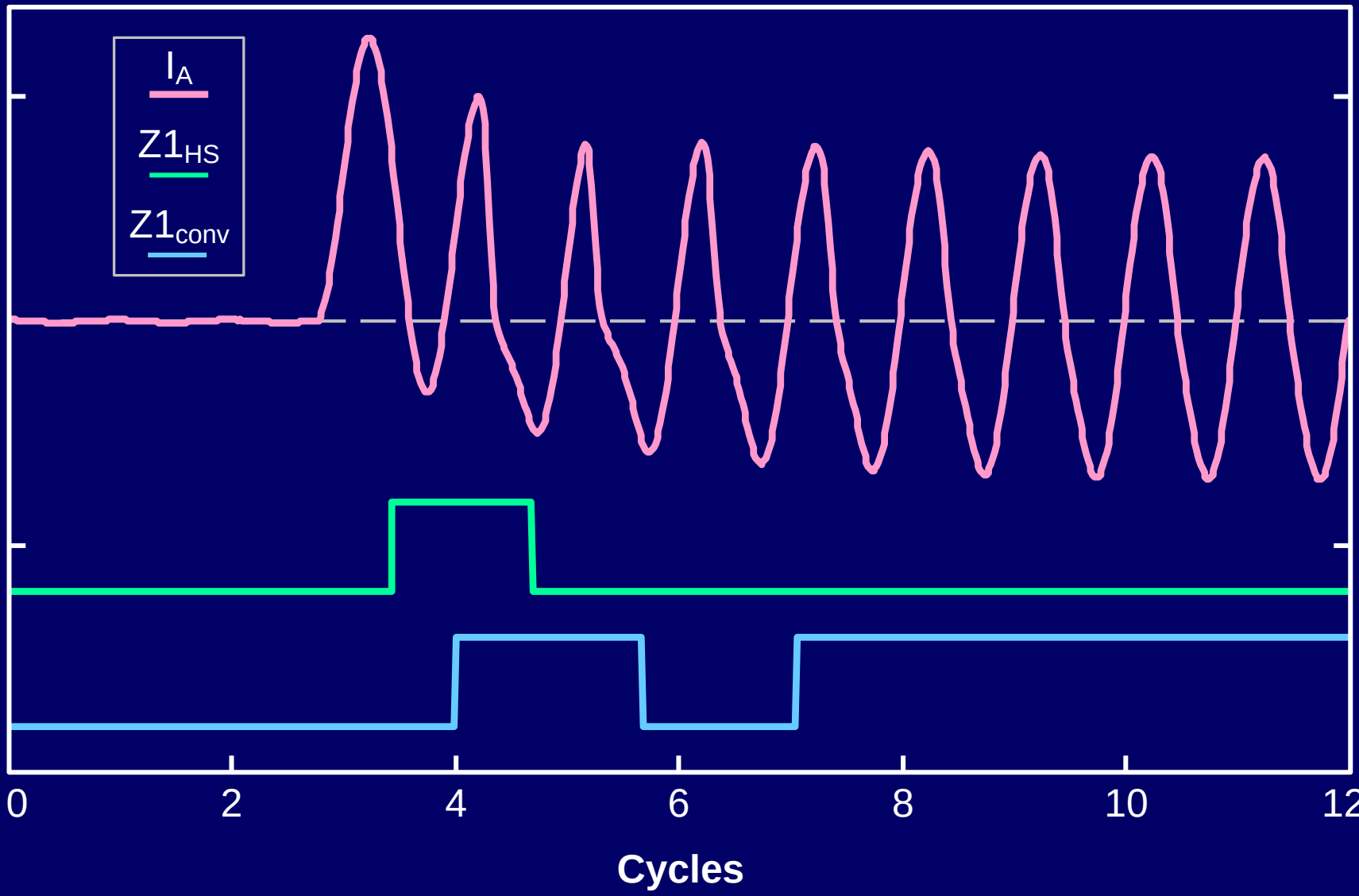
Zone 1 Operation for Close-in Fault
Six Times Maximum Burden



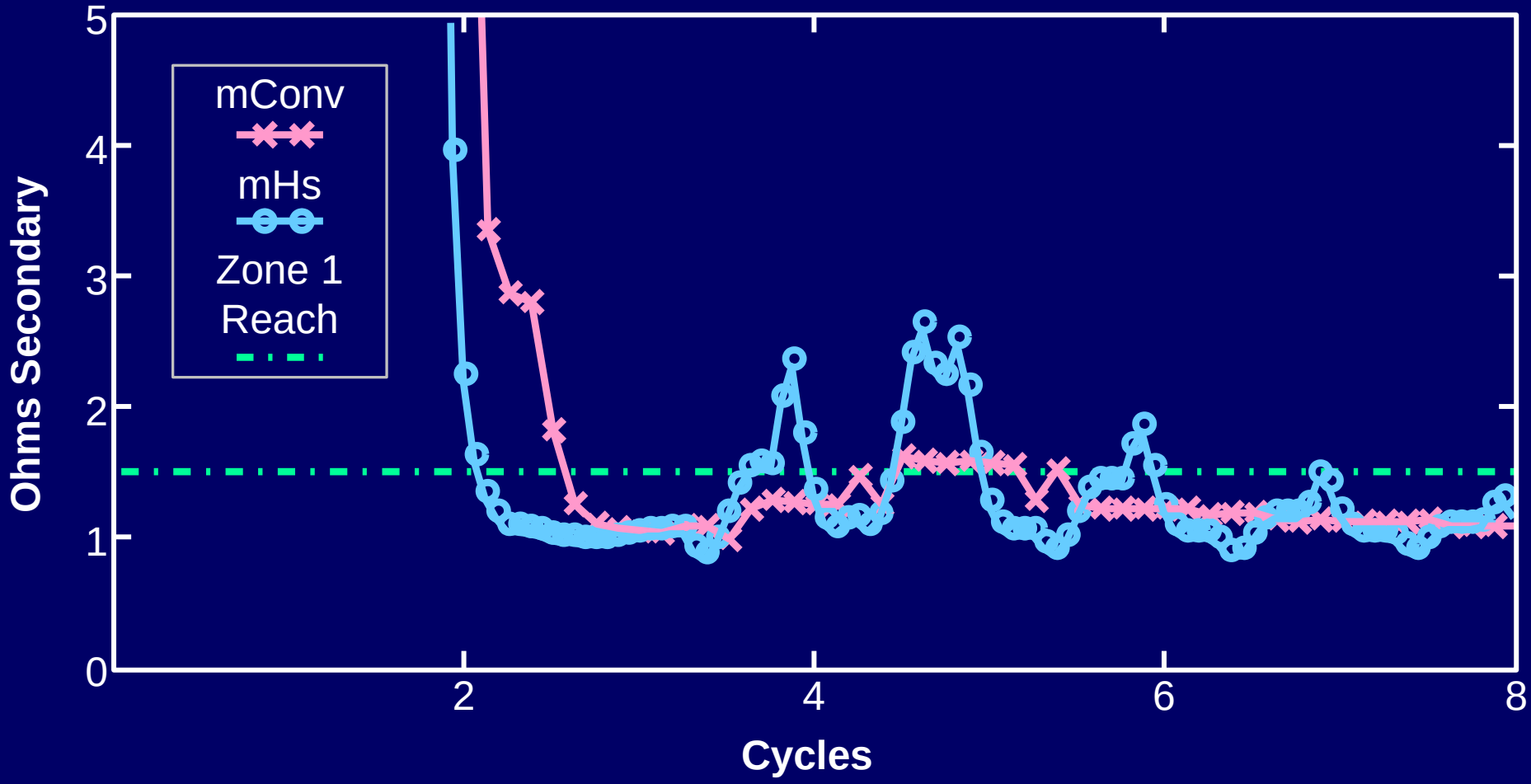
Measured Impedances for High-Speed and Conventional Elements



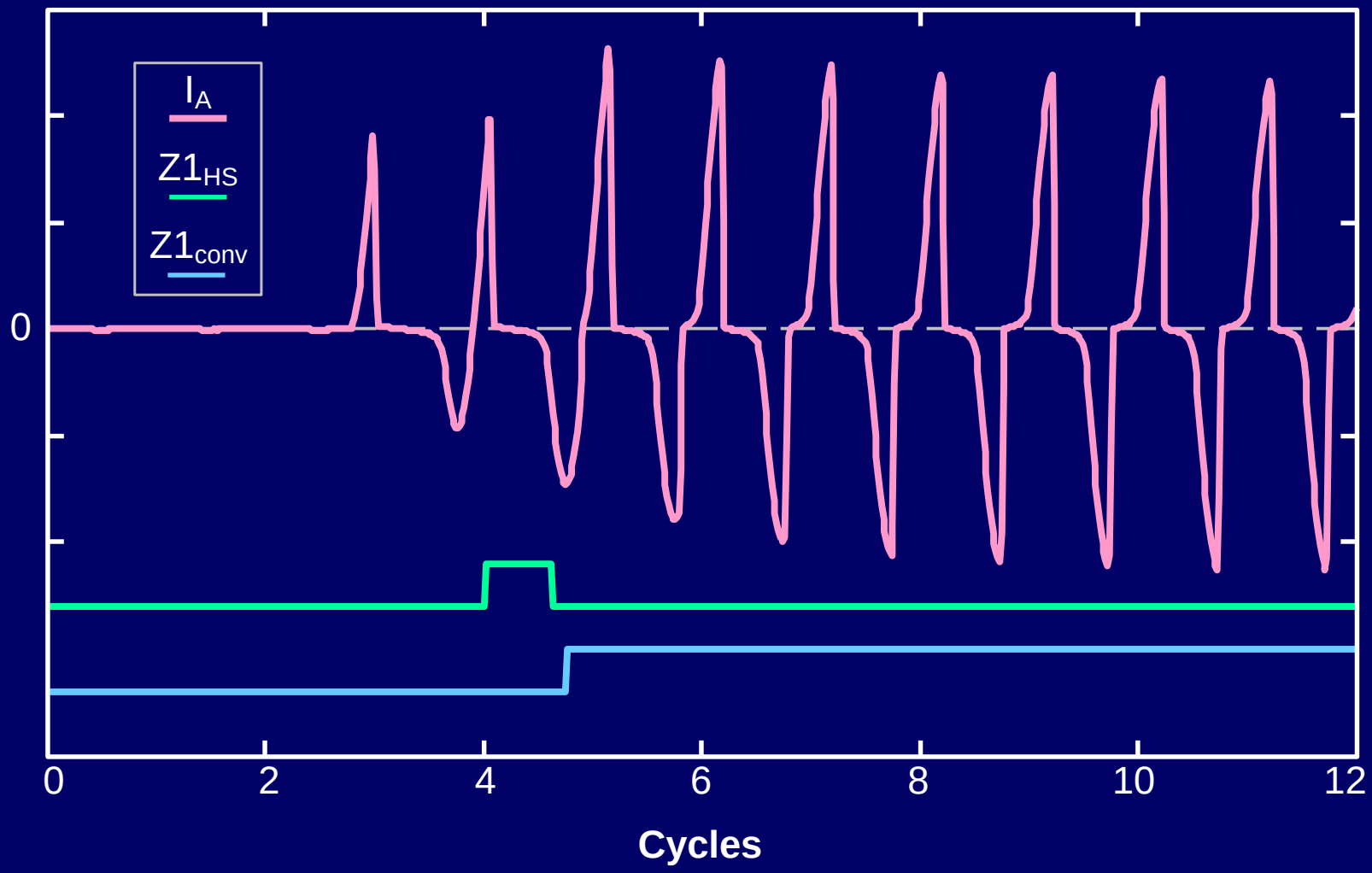
Zone 1 Response for Fault at 70% of Reach



Measured Impedances for Fault at 70% of Reach



Distance Element Response for Extreme Saturation – Close-in Fault



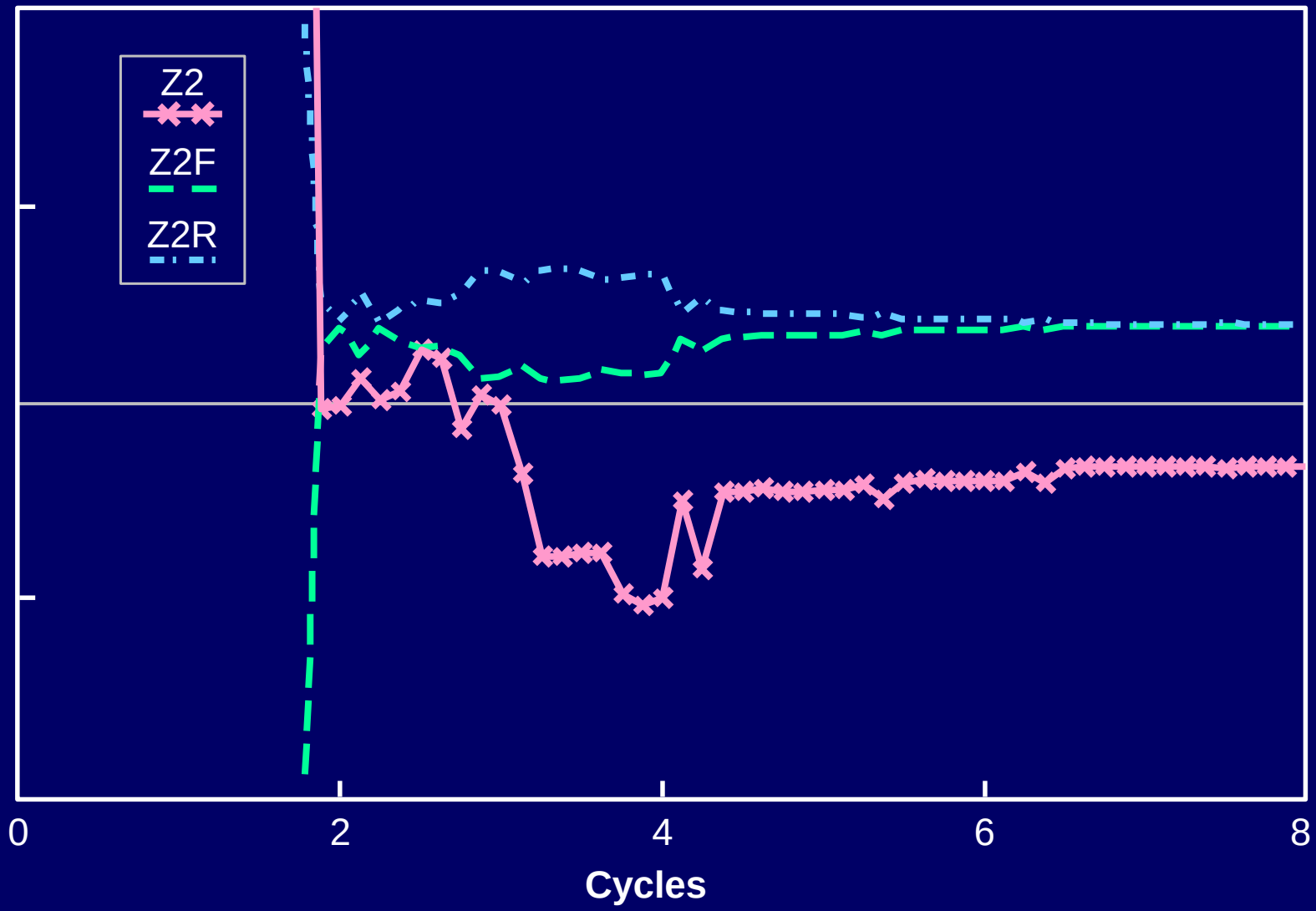
Directional Element Response

- Supervisory element for distance element logic
- Directional control for overcurrent elements
- Reliable directional operation

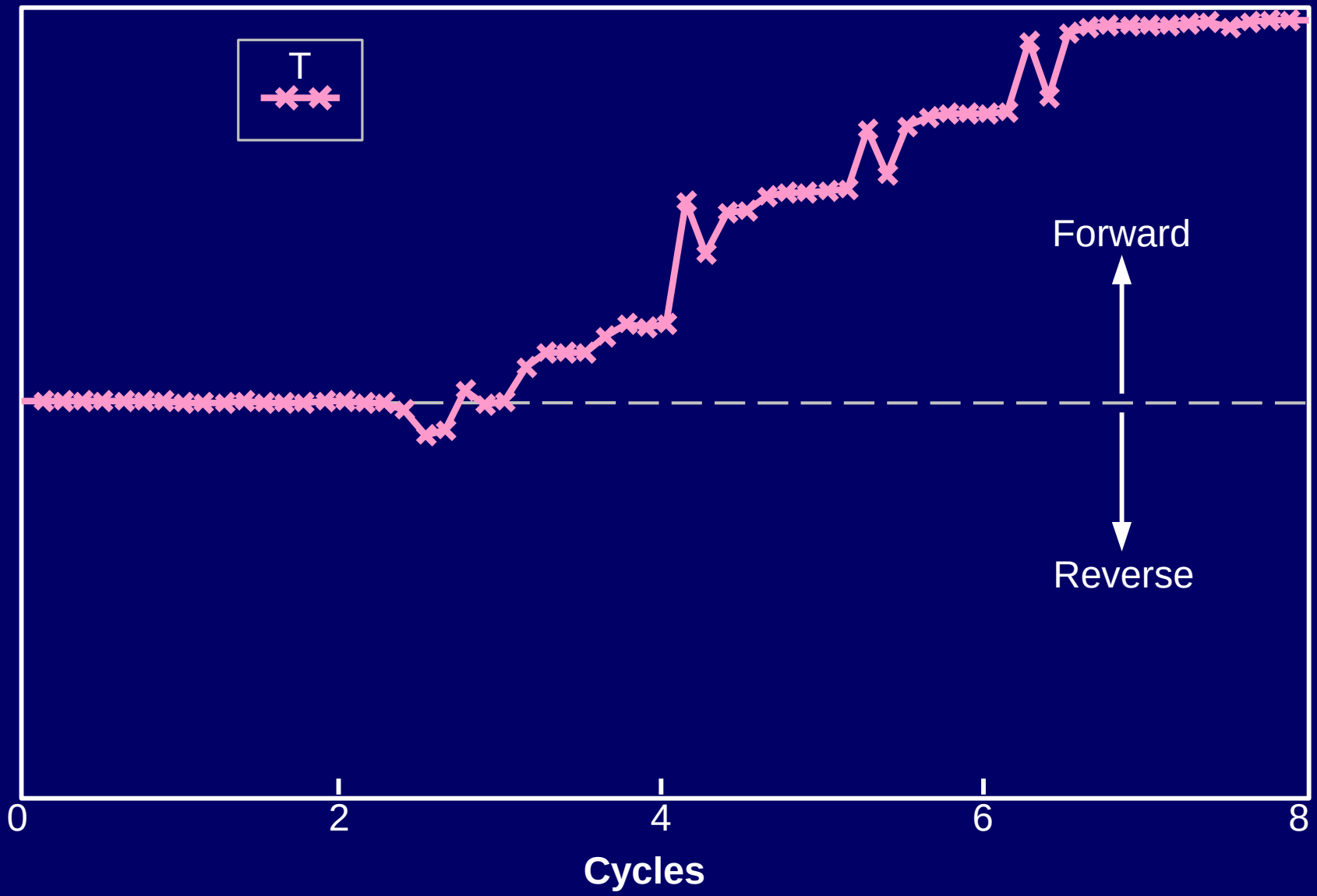
Directional Element Response

- Impedance-based and torque-based directional elements using negative-sequence quantities
- Increase burden in element incorrectly operates or slows down significantly

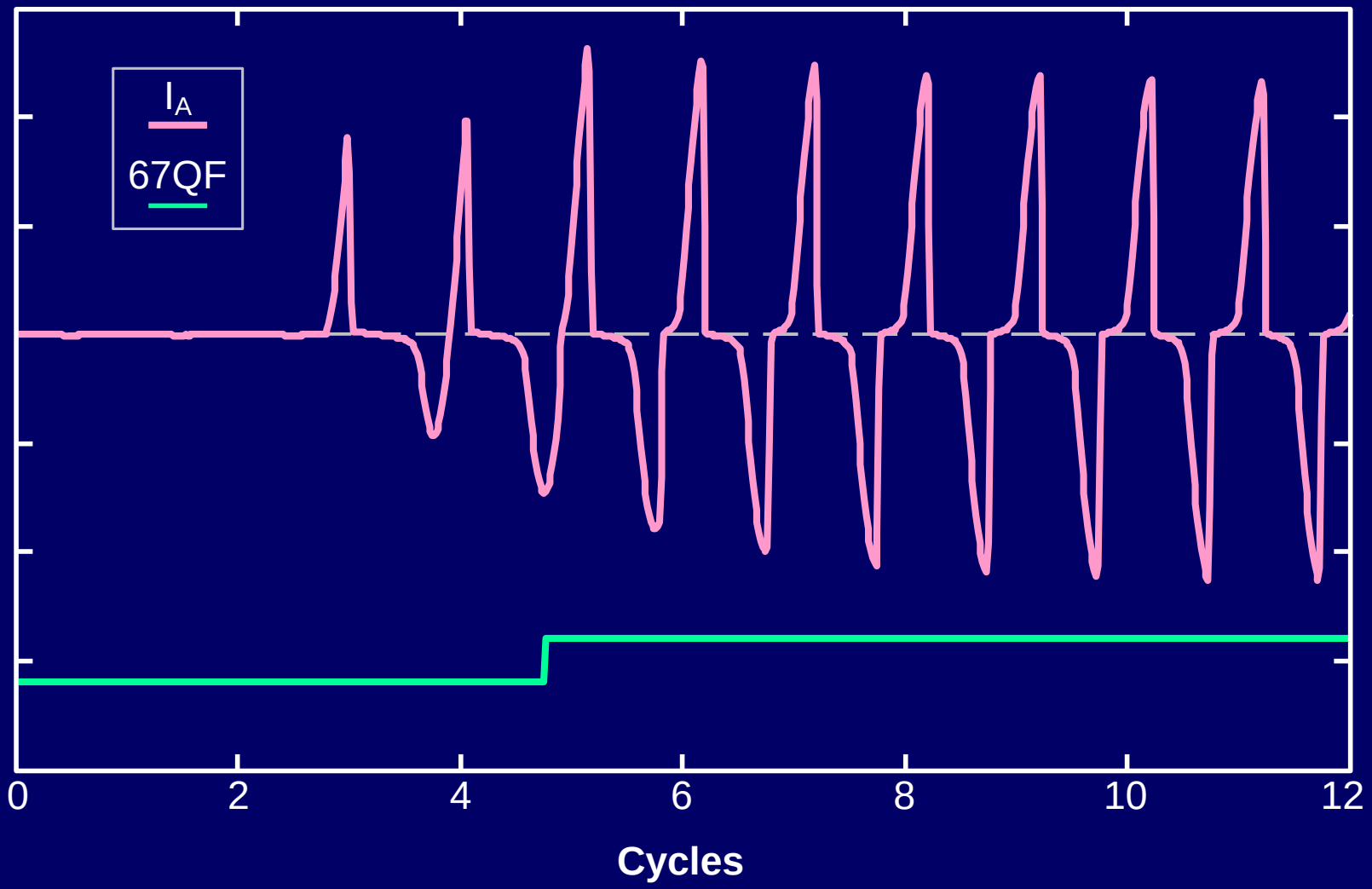
Impedance-Based Directional Element Response – Ten Times Maximum



Torque-Based Directional Element – Ten Times Maximum



Extreme CT Saturation Slows Down Directional Decision



Recommendations

- Determine CT sizing requirements maximum fault current; typically close-in fault
- The following formula ensures secure distance and directional operation:

$$Z_{sb} \leq \frac{6 \cdot V_k}{\left| \frac{X}{R} + 1 \right| \cdot I_{sf}}$$

Conclusions

- CT saturation results in current phase shift and magnitude reduction
- Distance elements underreach and increase in operating time
- Directional elements are secure, but may slow down
- Check CT suitability for high magnitude faults or faults at critical locations