

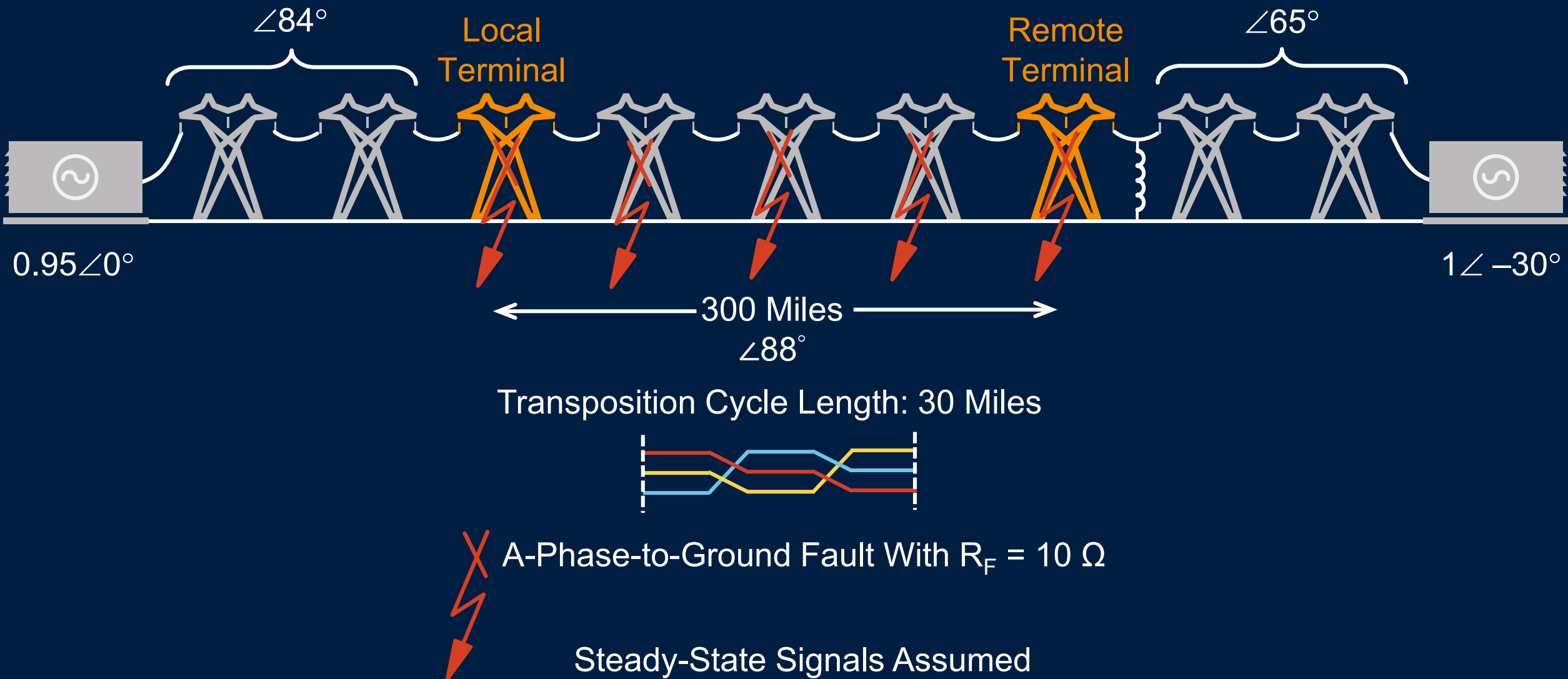
Computationally Efficient Methods for Improved Double-Ended Transmission Line Fault Locating

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Schweitzer Engineering Laboratories, Inc.

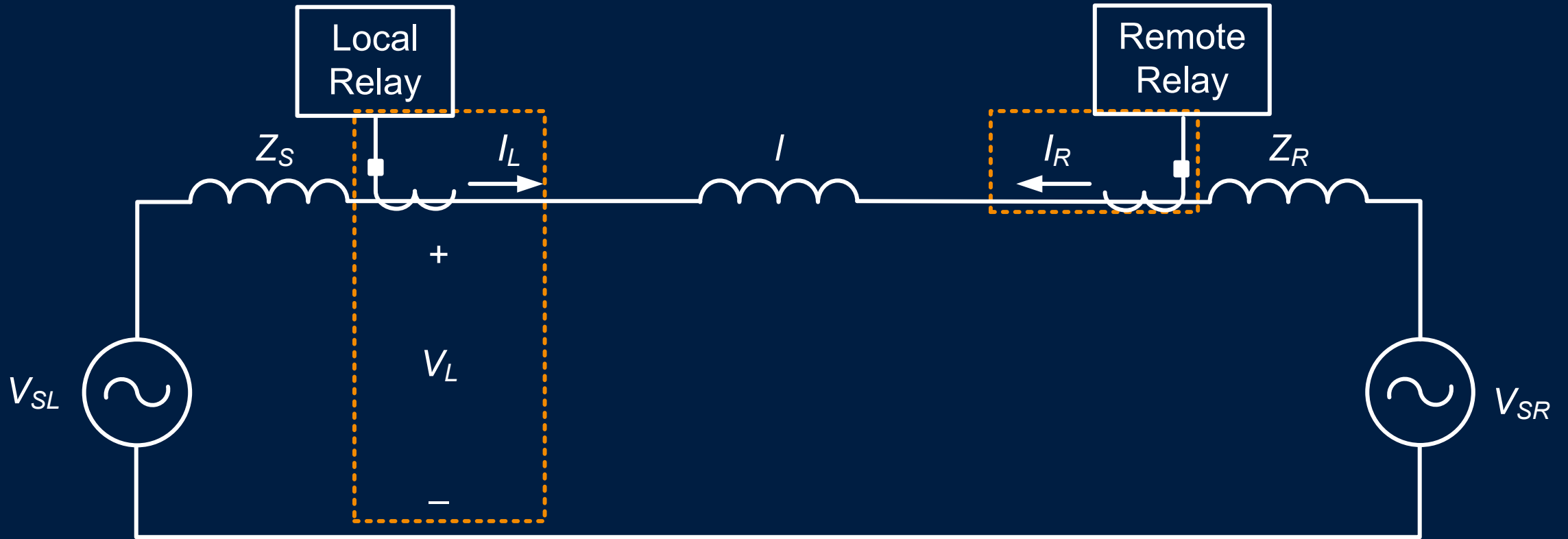
Overview

- FL methods with local voltages and currents and remote currents
- FL methods with local and remote voltages and currents
- Field event results
- Conclusions

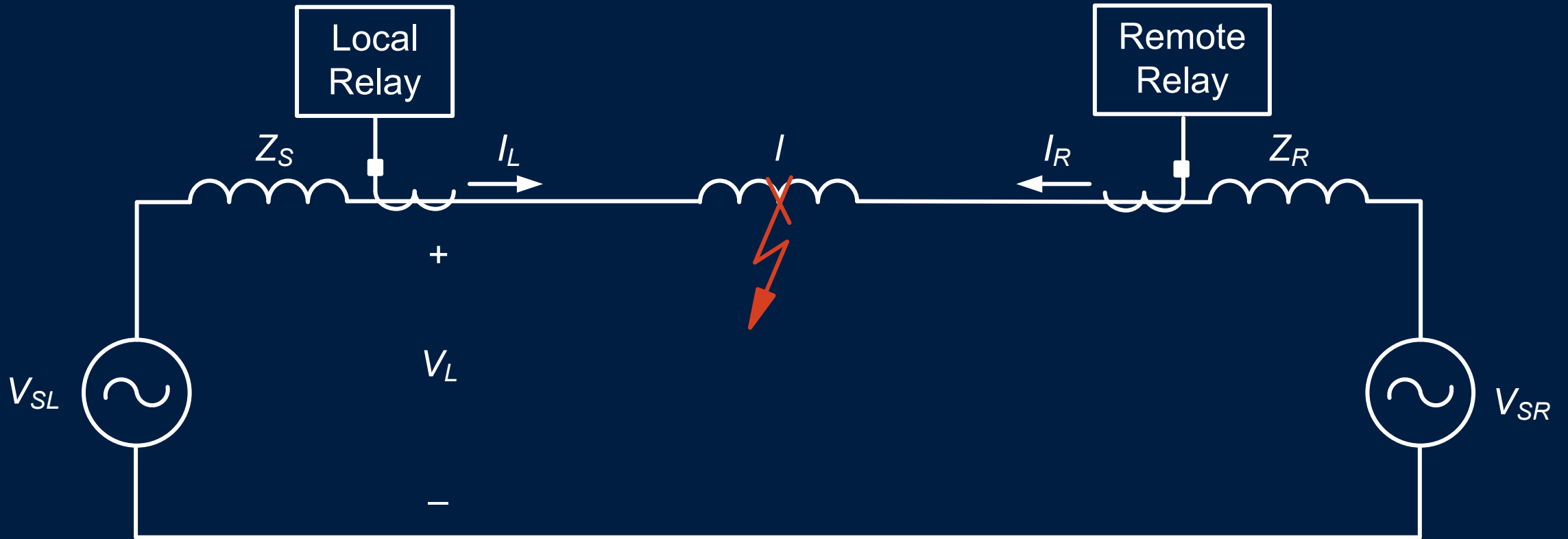
Power System Model Used to Analyze Fault-Locating Methods



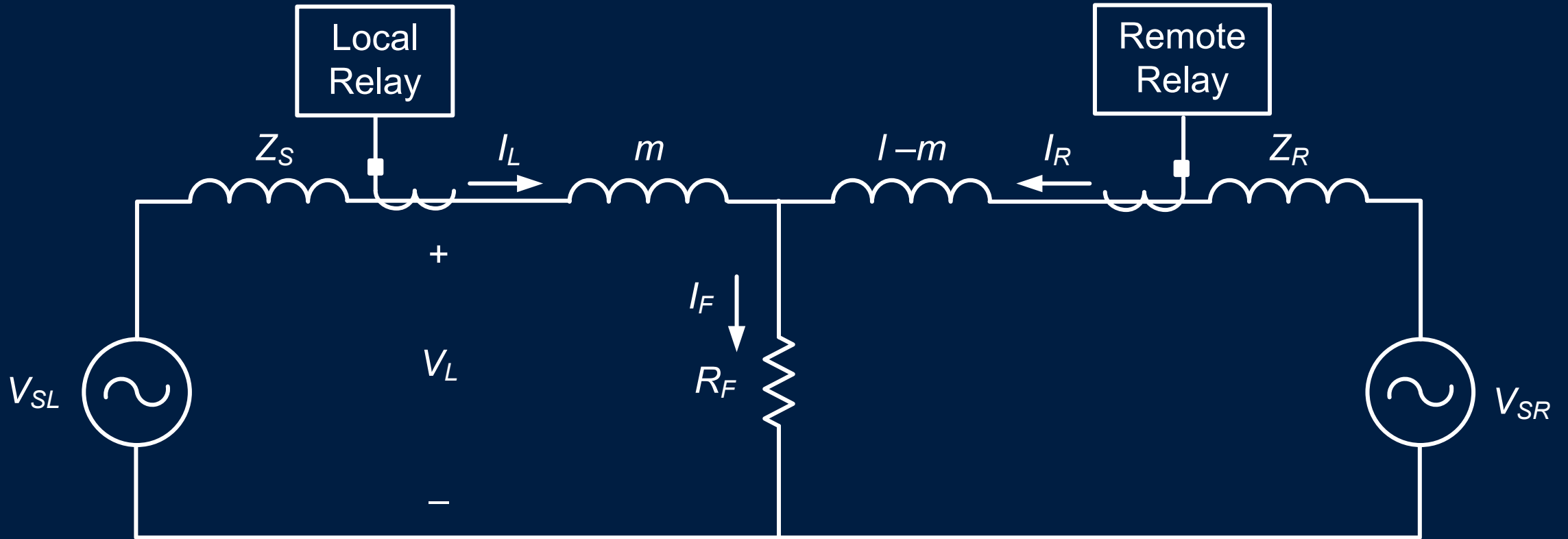
Estimate Fault Locating With Local Voltages and Currents and Remote Currents



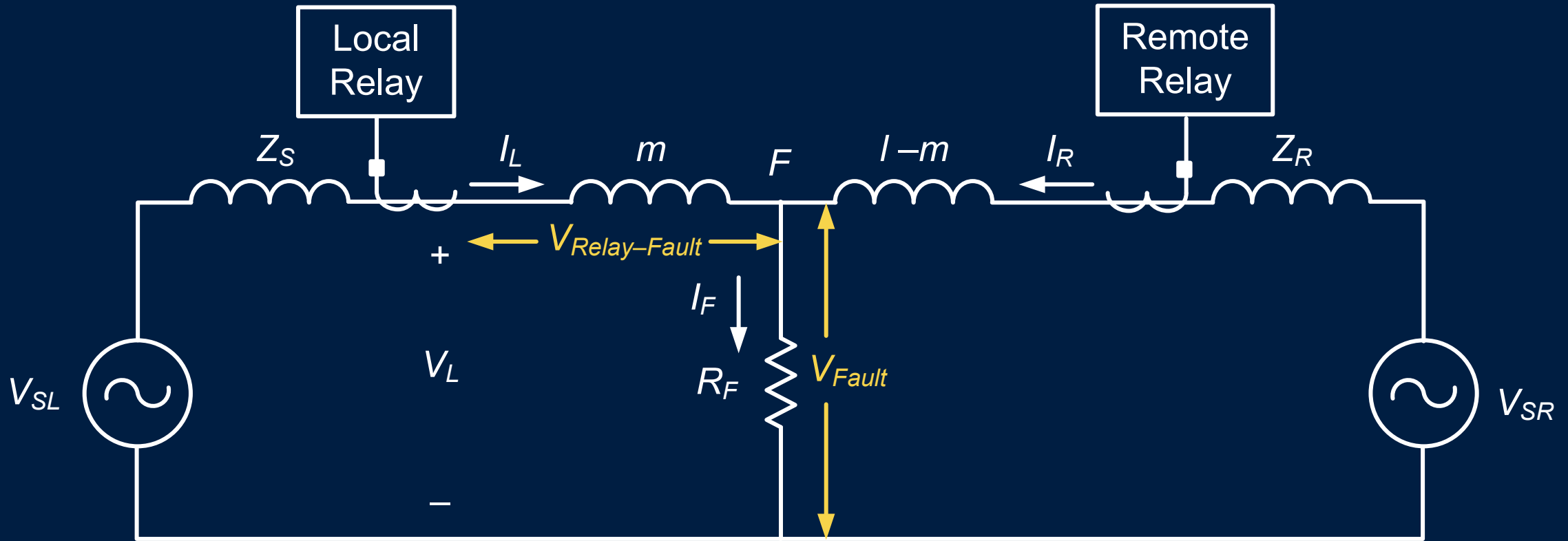
Estimate Fault Locating With Local Voltages and Currents and Remote Currents



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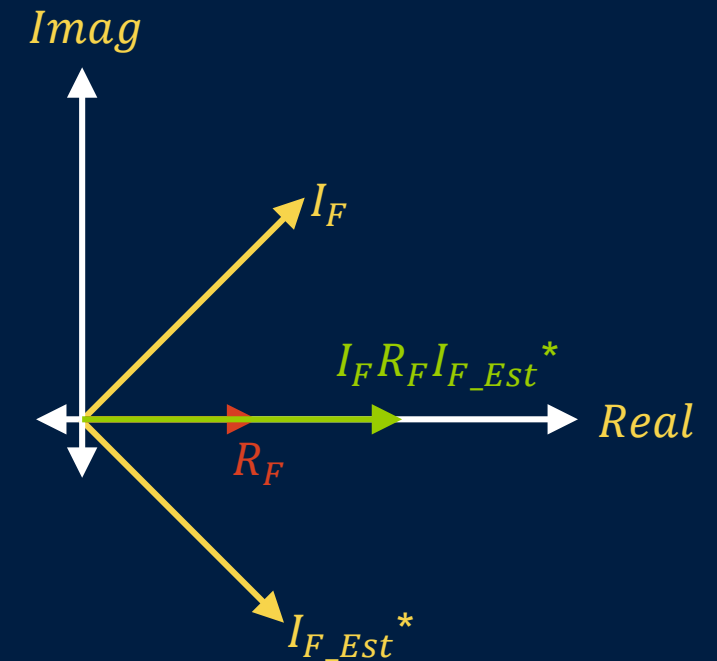


$$V_L = \underbrace{V_{Relay-Fault}}_1 + \underbrace{I_F R_F}_2$$

Fault-Locating Accuracy Is Affected by Some Constraints

$$V_{Ph} = \underbrace{V_{Relay-Fault}}_1 + \underbrace{I_F R_F}_2$$

$$Imag[V_{Ph} I_{F_Est}^*] = \underbrace{Imag[V_{Relay_Fault} I_{F_Est}^*]}_1 + \underbrace{Imag[I_F R_F I_{F_Est}^*]}_2$$

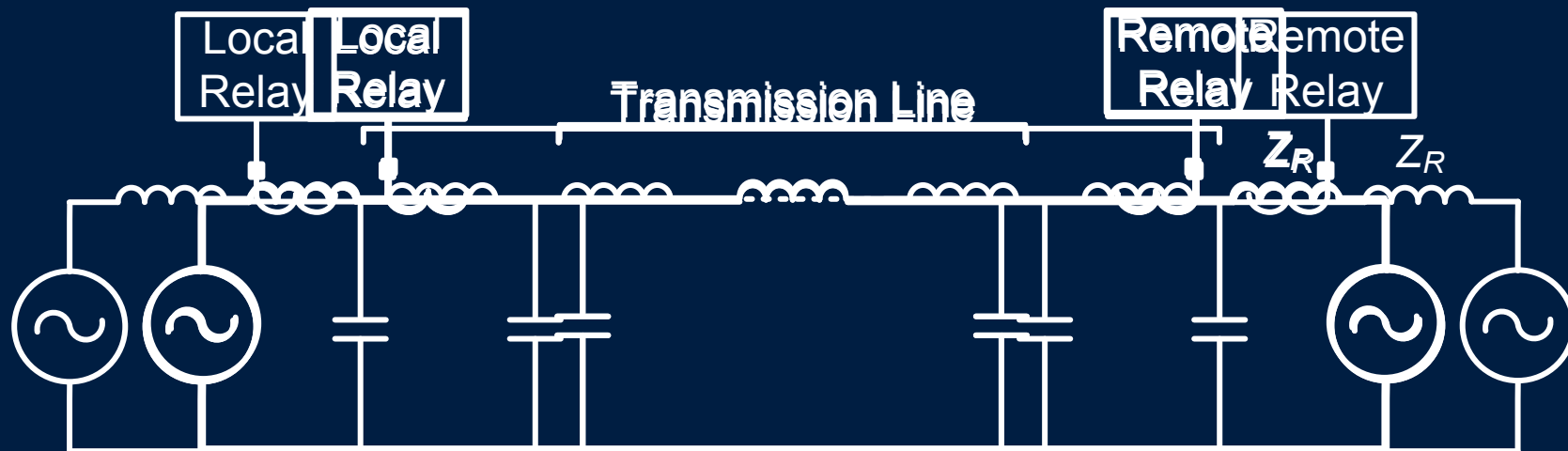


Fault locating accuracy depends on:

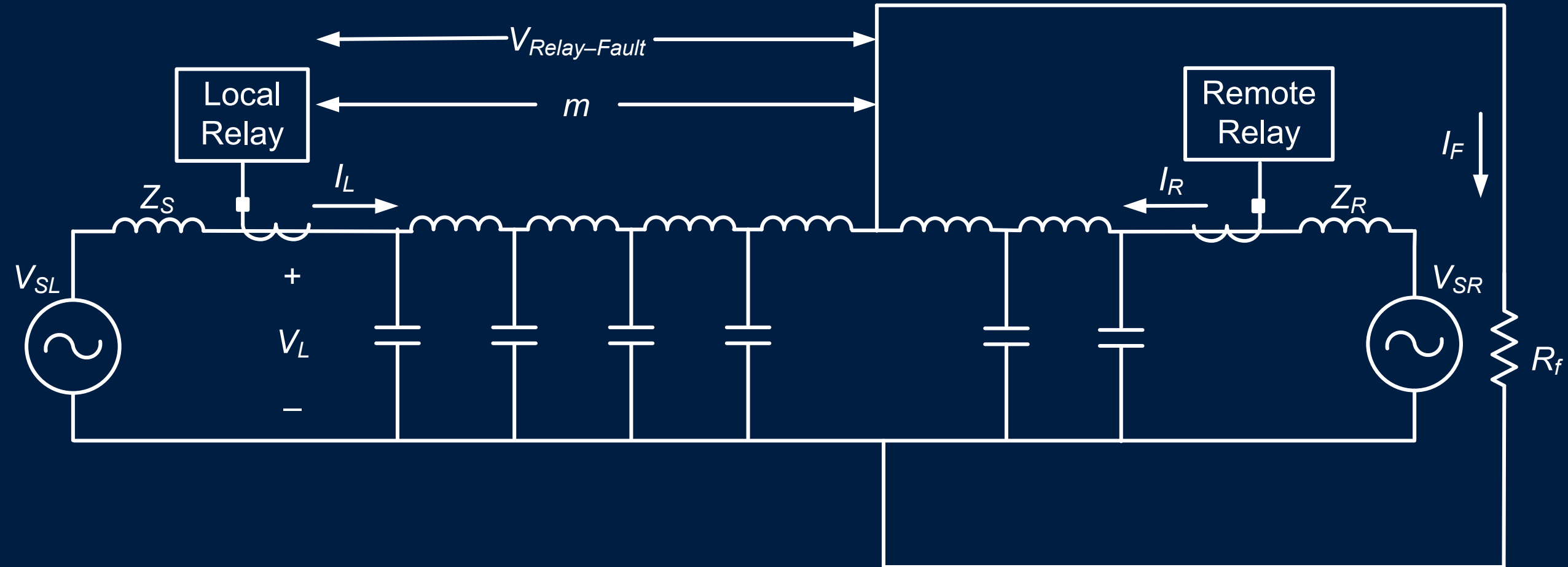
- Accurate calculation of $V_{Relay-Fault}$
- Accurate estimation of $\angle I_{F_Est}$

Evaluate Fault-Locating Methods With Local Voltages and Currents and Remote Currents

- Takagi method
- Takagi method with π line model
- Takagi method with π long-line model
- Proposed method (distributed line model)

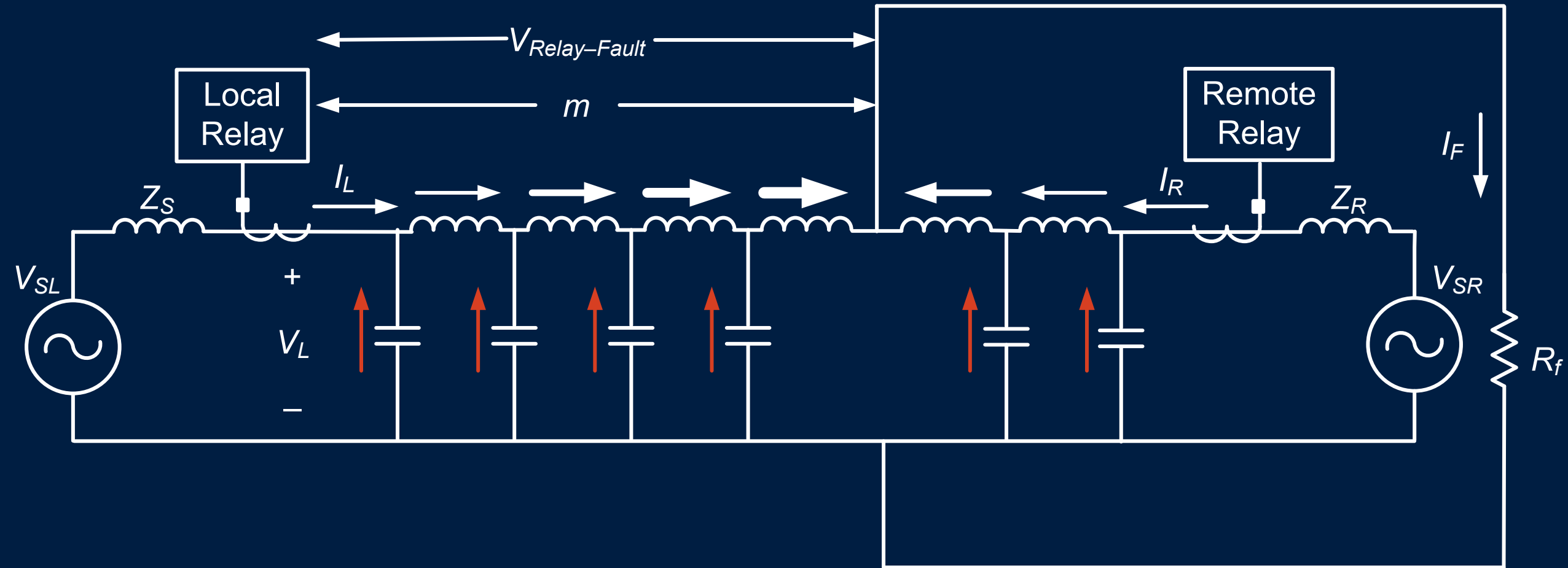


Investigate the Cause of $V_{\text{Relay-Fault}}$ Error in the Takagi Method



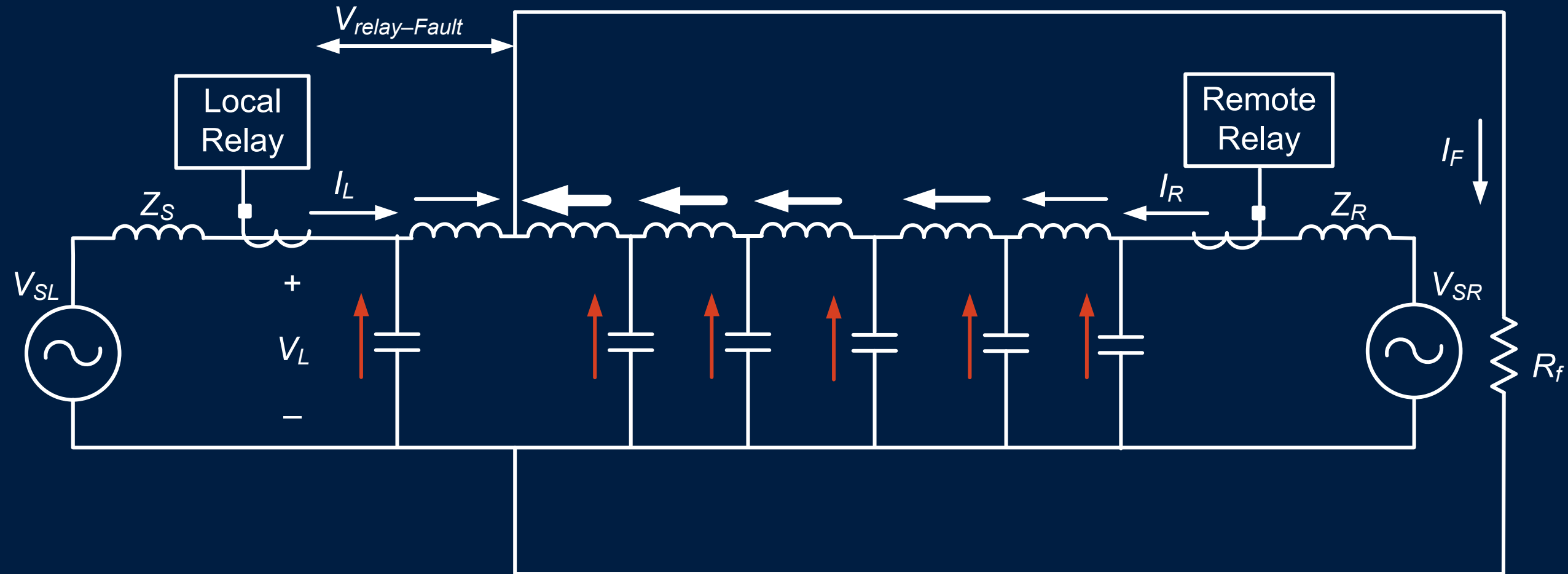
$$V_{\text{Relay-Fault}} = mZ_L I_L$$

Investigate the Cause of $V_{\text{Relay-Fault}}$ Error in the Takagi Method



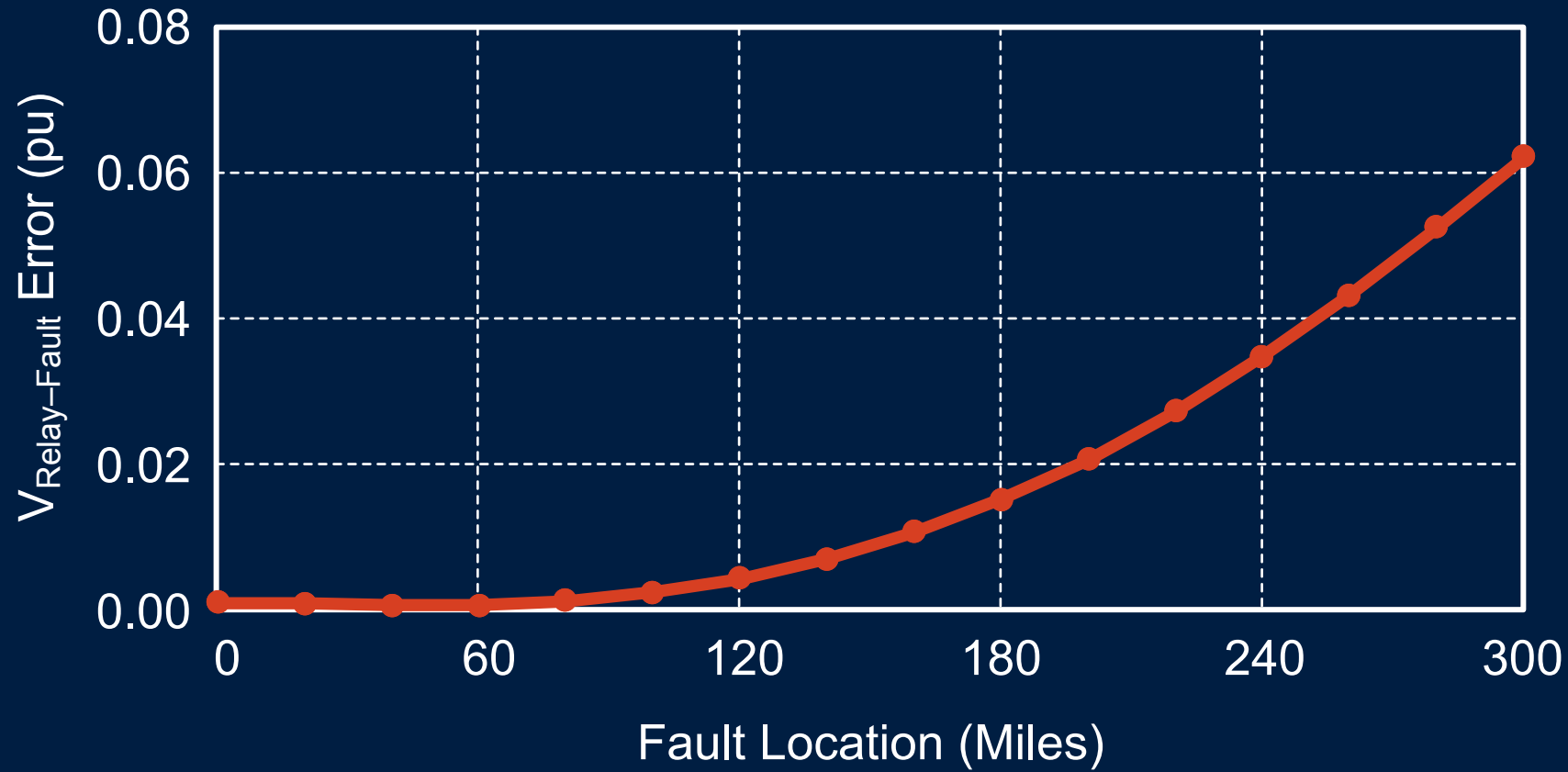
$$V_{\text{Relay-Fault}} = mZ_L I_L$$

Investigate the Cause of $V_{\text{Relay-Fault}}$ Error in the Takagi Method

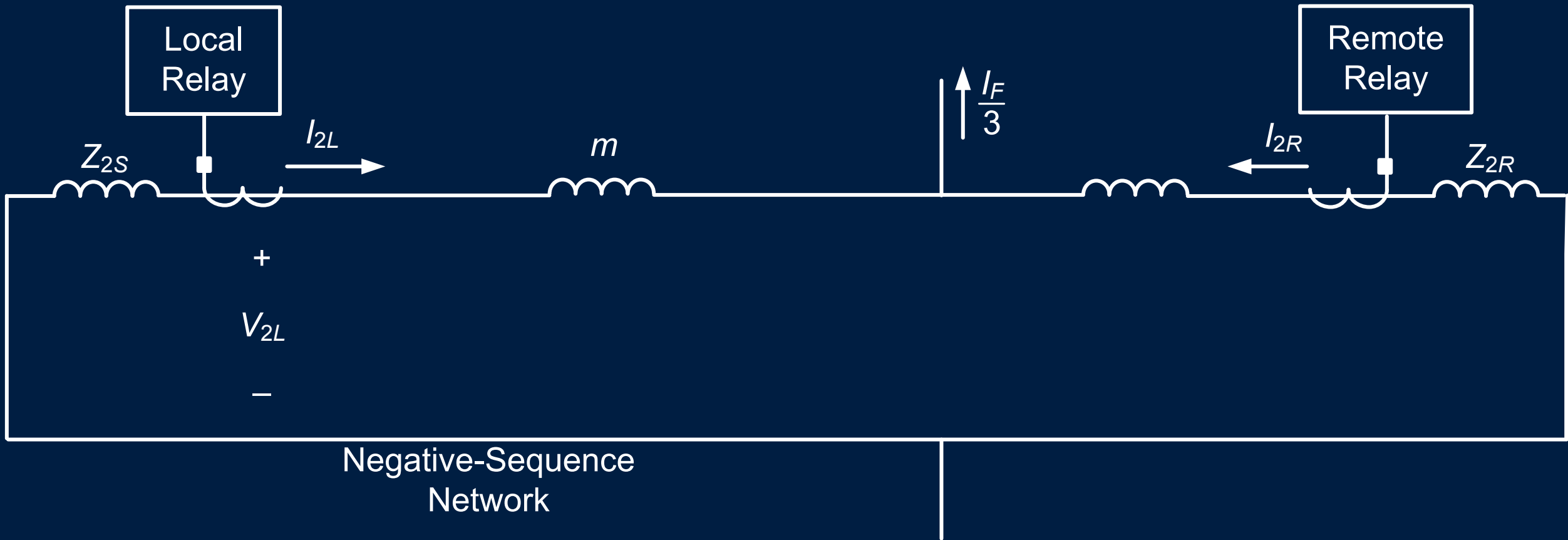


$$V_{\text{Relay-Fault}} = mZ_L I_L$$

Examine $V_{\text{Relay-Fault}}$ Error in the Takagi Method

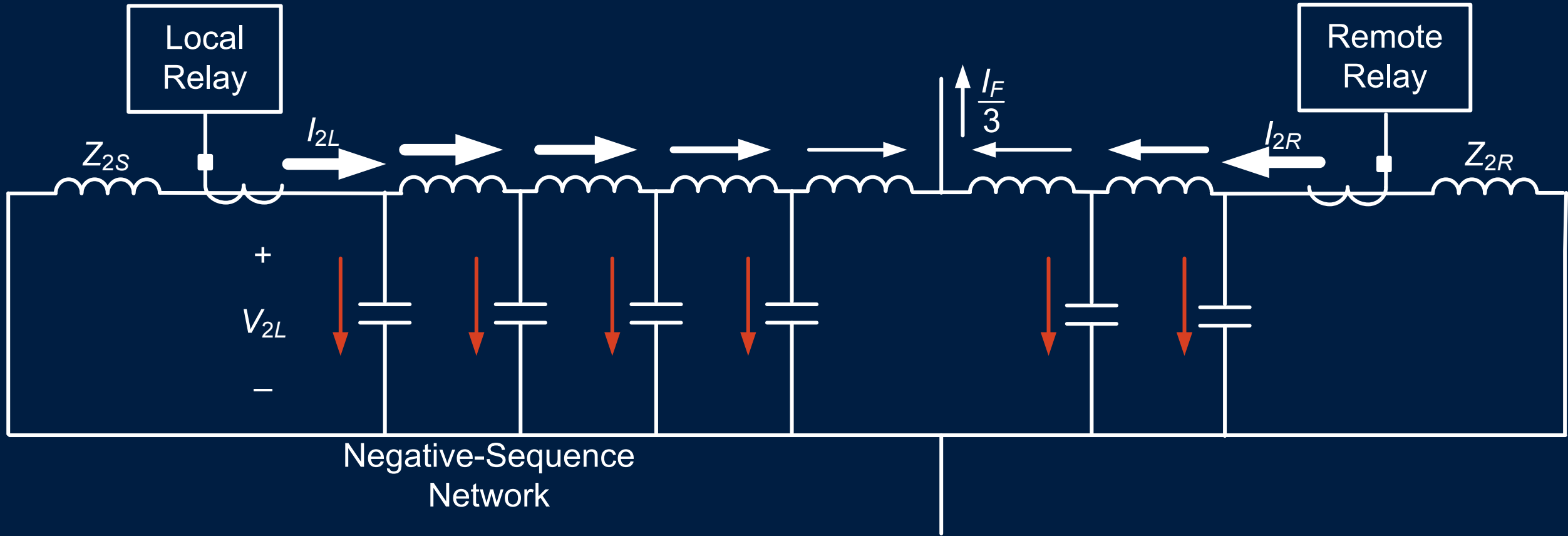


Evaluate $\angle I_{F_Est}$ in the Takagi Method



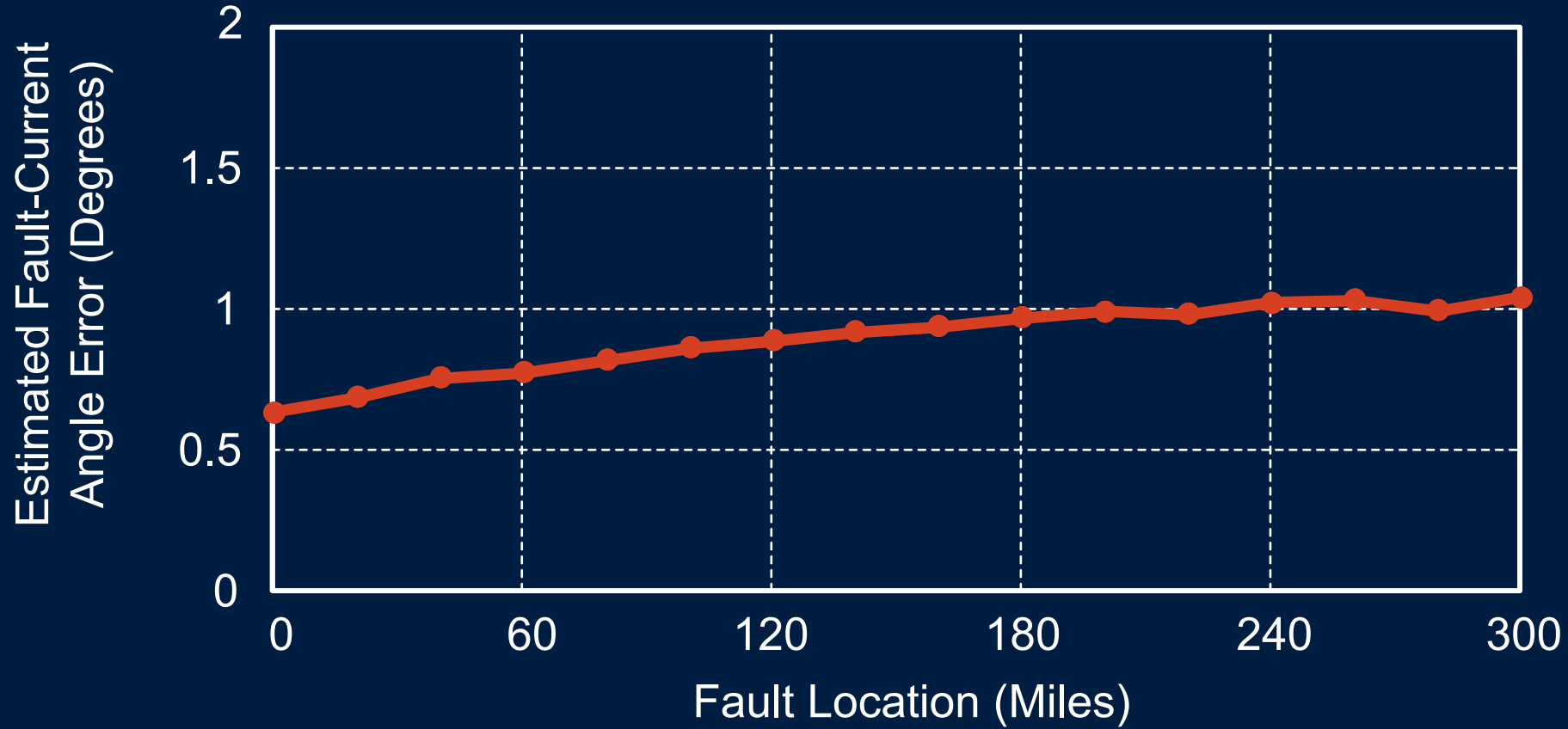
$$\angle I_{F_Est} = \angle(I_{2L} + I_{2R})$$

Investigate the Cause of $\angle I_{F_Est}$ Error in the Takagi Method

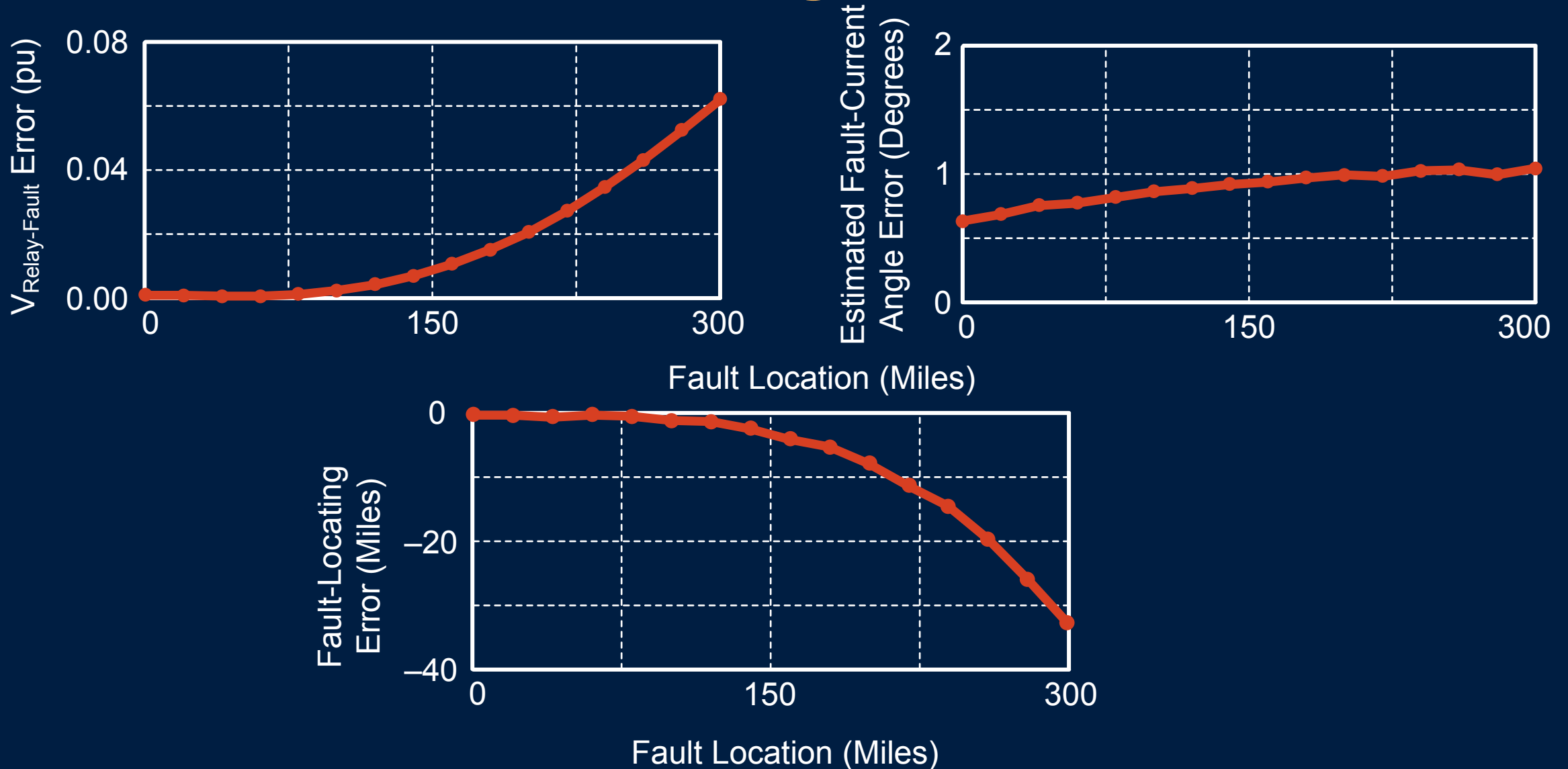


$$\angle I_{F_Est} = \angle(I_{2L} + I_{2R})$$

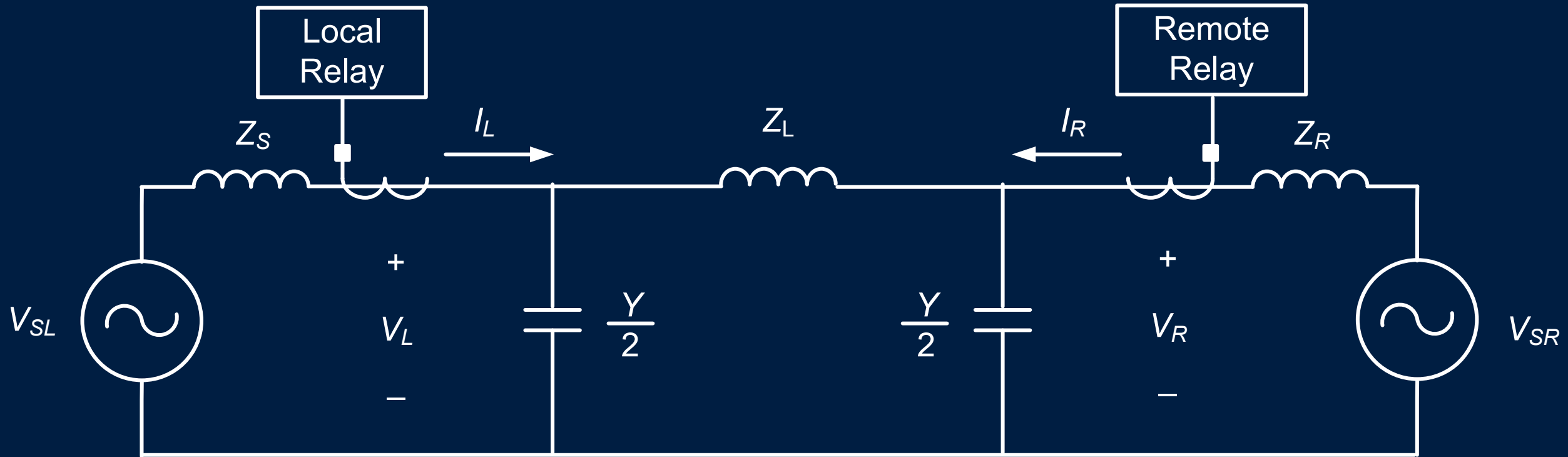
Examine $\angle I_{F_Est}$ Error in the Takagi Method



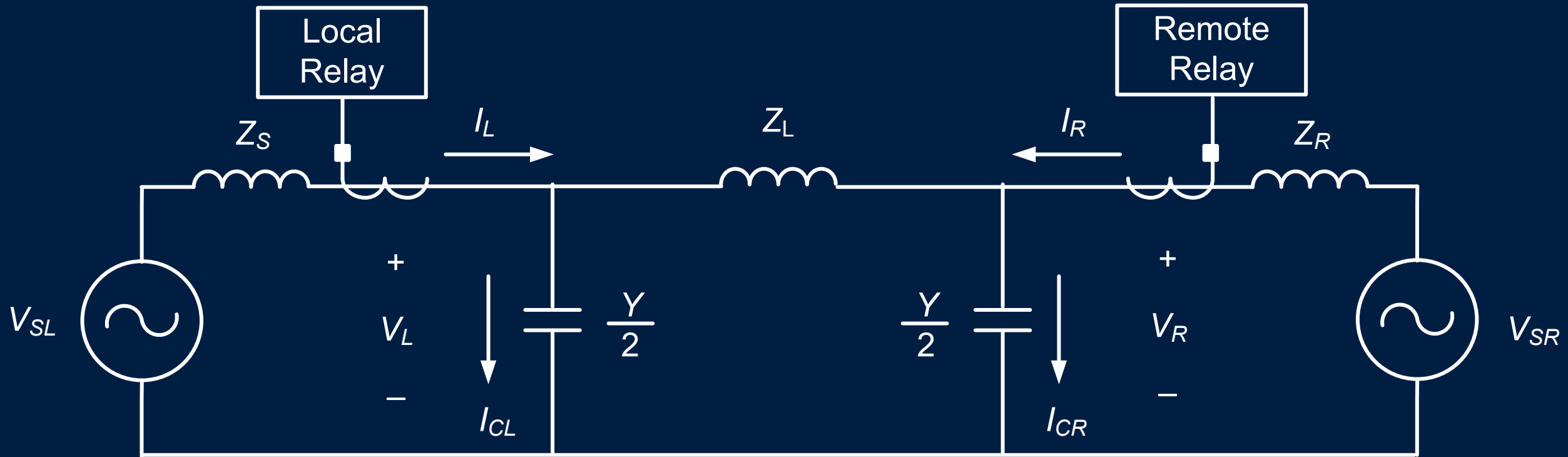
Examine Total Fault-Locating Error in the Takagi Method



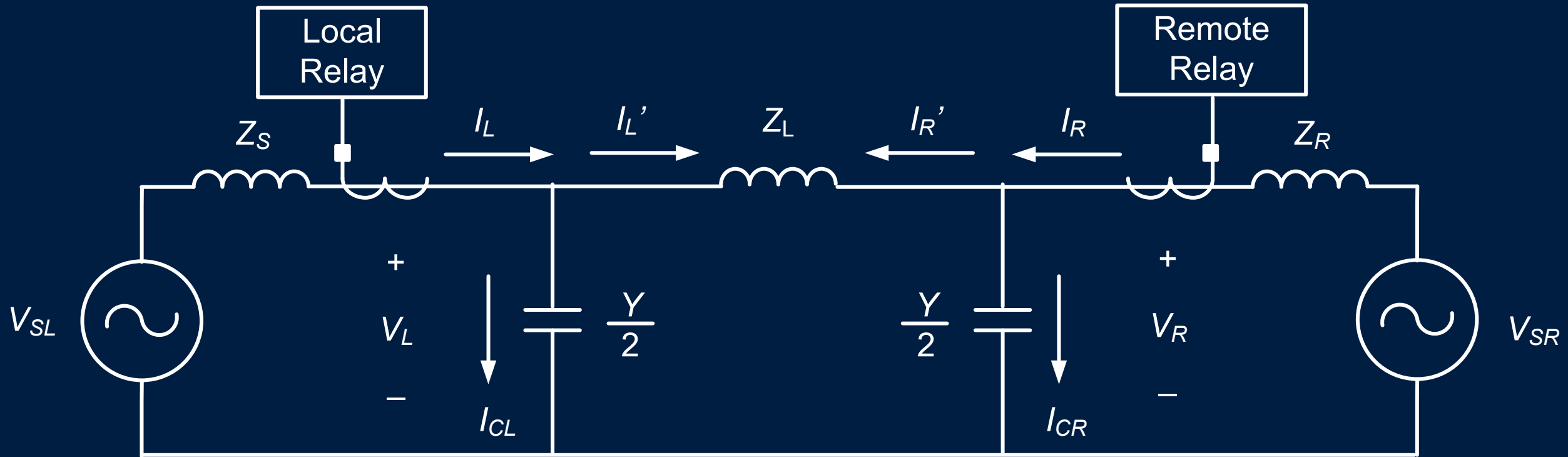
Interpret the Takagi Method With π Line Model



Interpret the Takagi Method With π Line Model

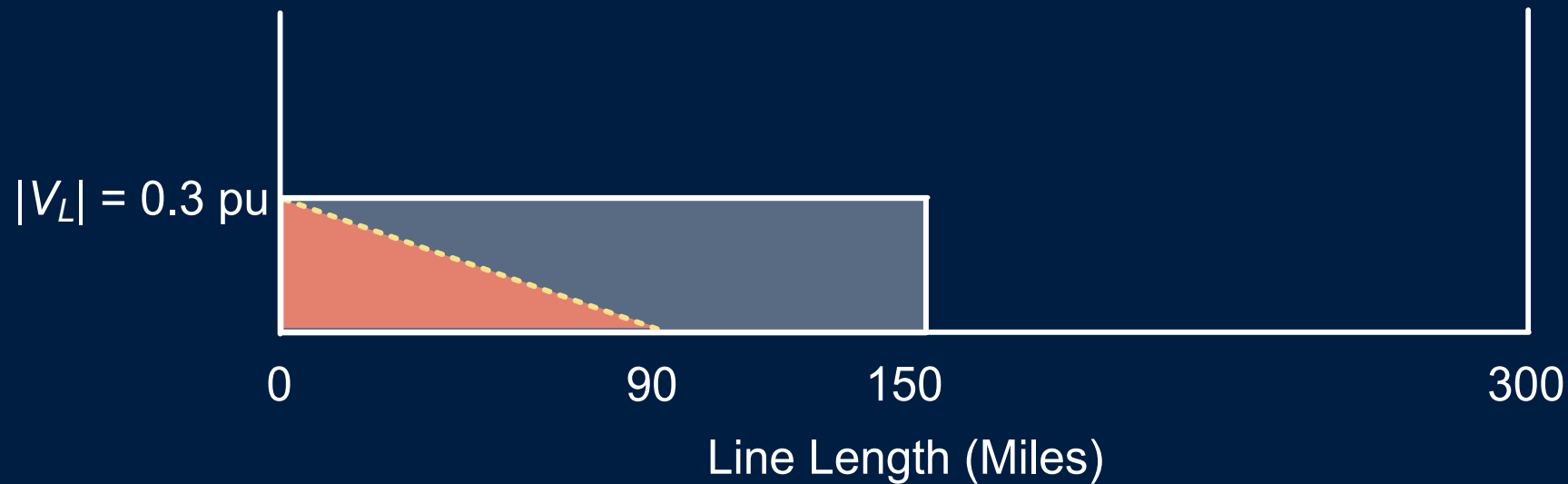


Interpret the Takagi Method With π Line Model

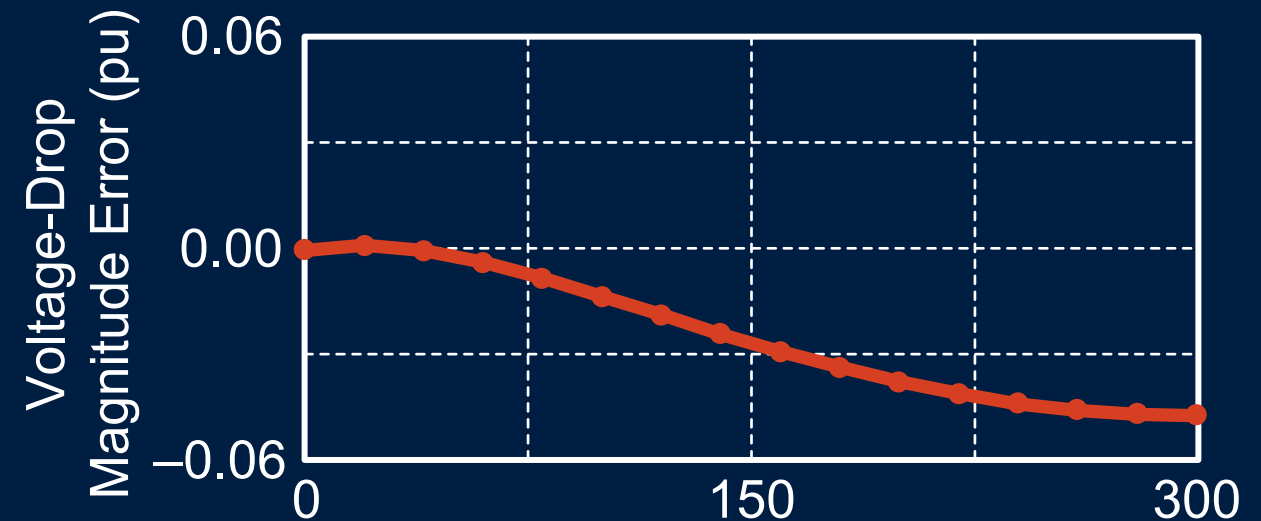


I_L' and I_R' : Compensated Line Currents

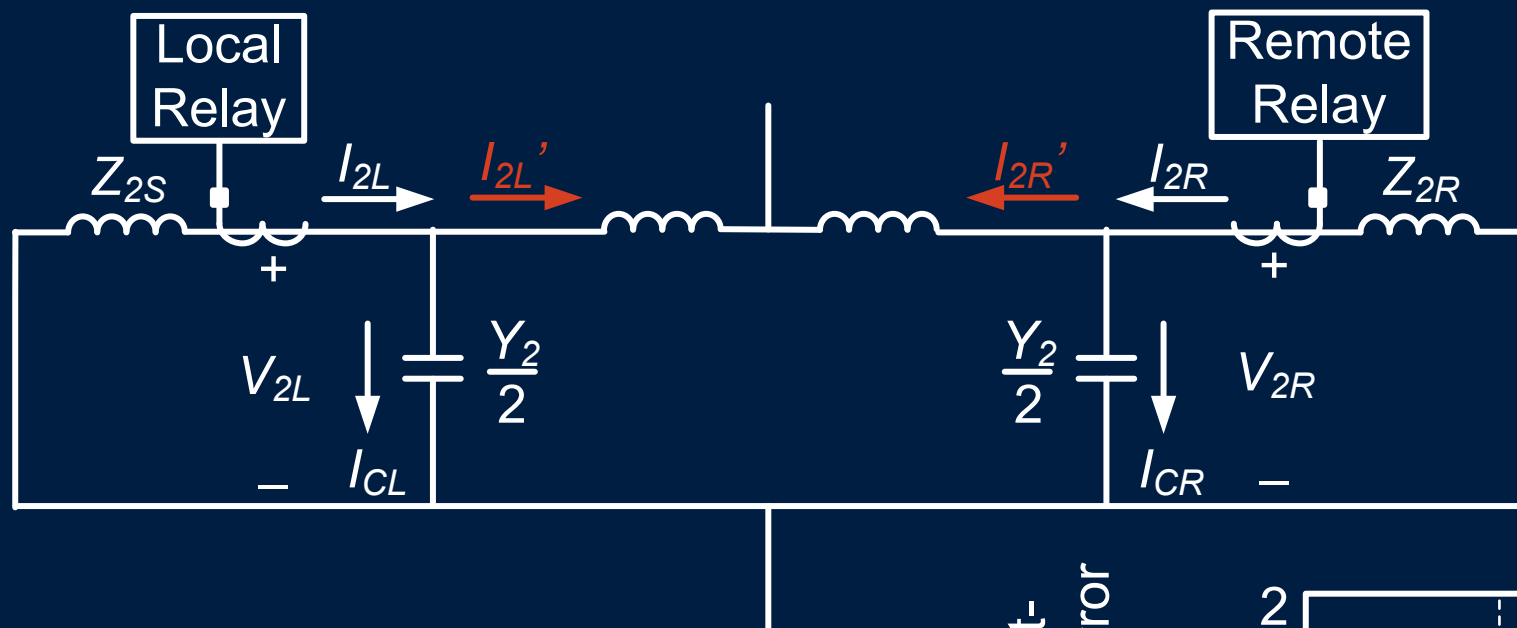
Investigate the Cause of $V_{\text{Relay-Fault}}$ Error in the Takagi Method With π Line Model



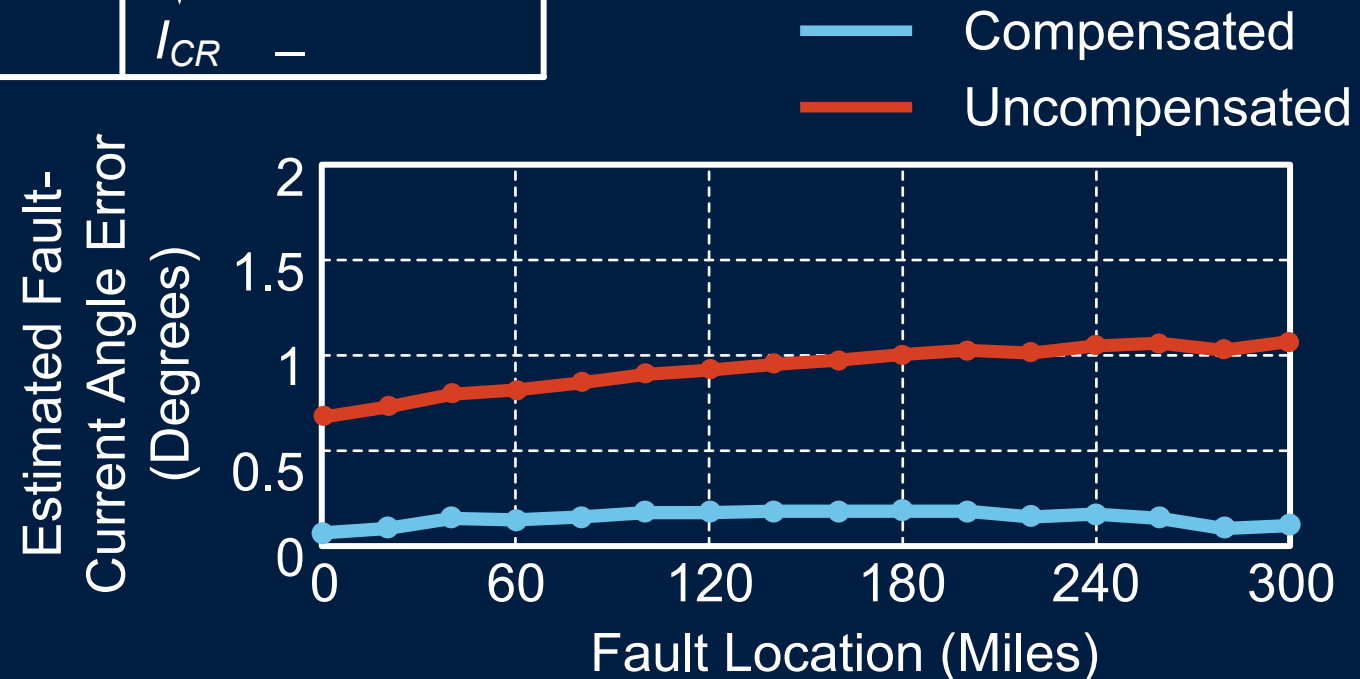
$$V_{\text{Relay-Fault}} = mZ_L I_L'$$



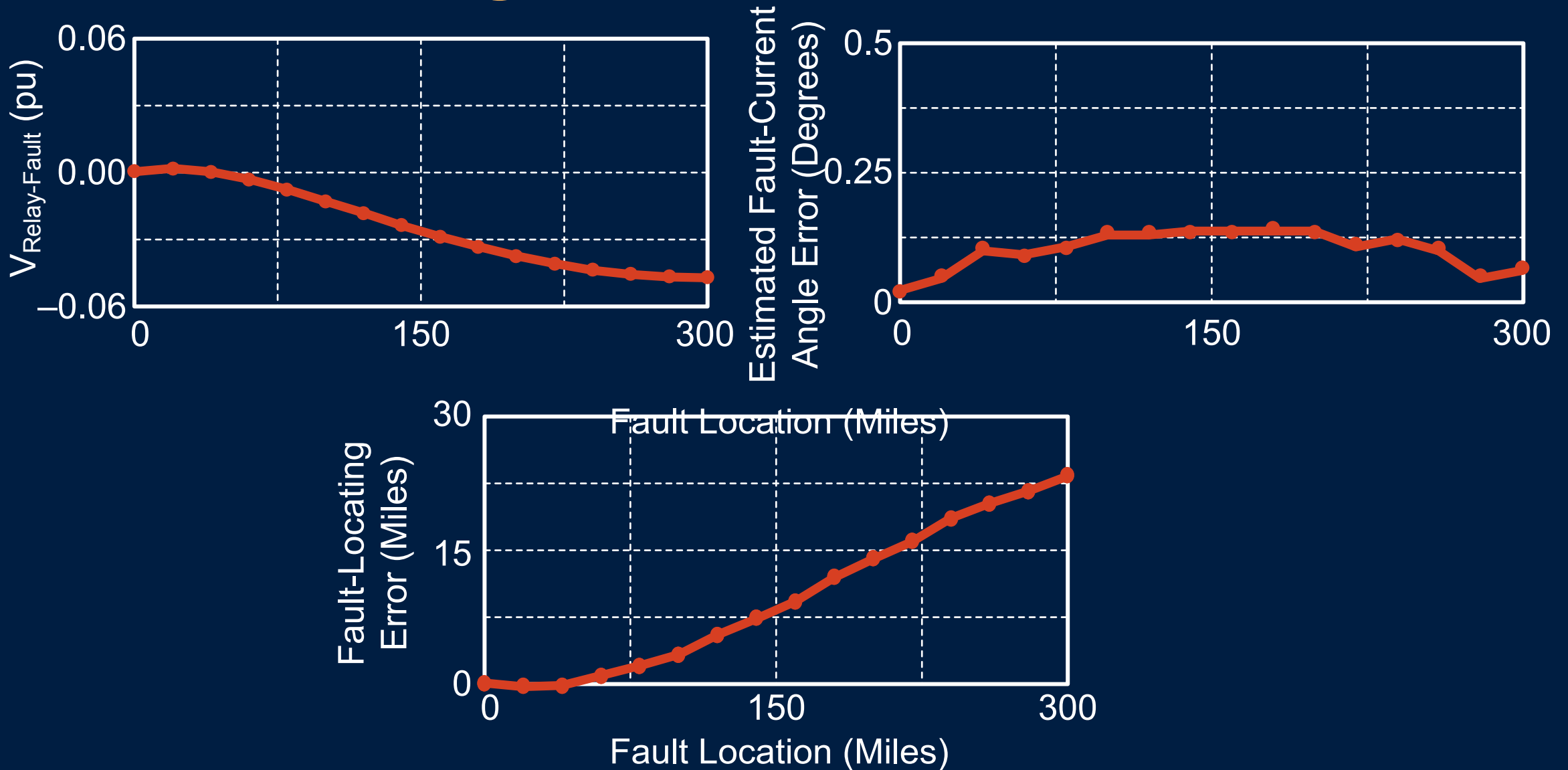
Examine $\angle I_{F_Est}$ Error in the Takagi Method with π Line Model



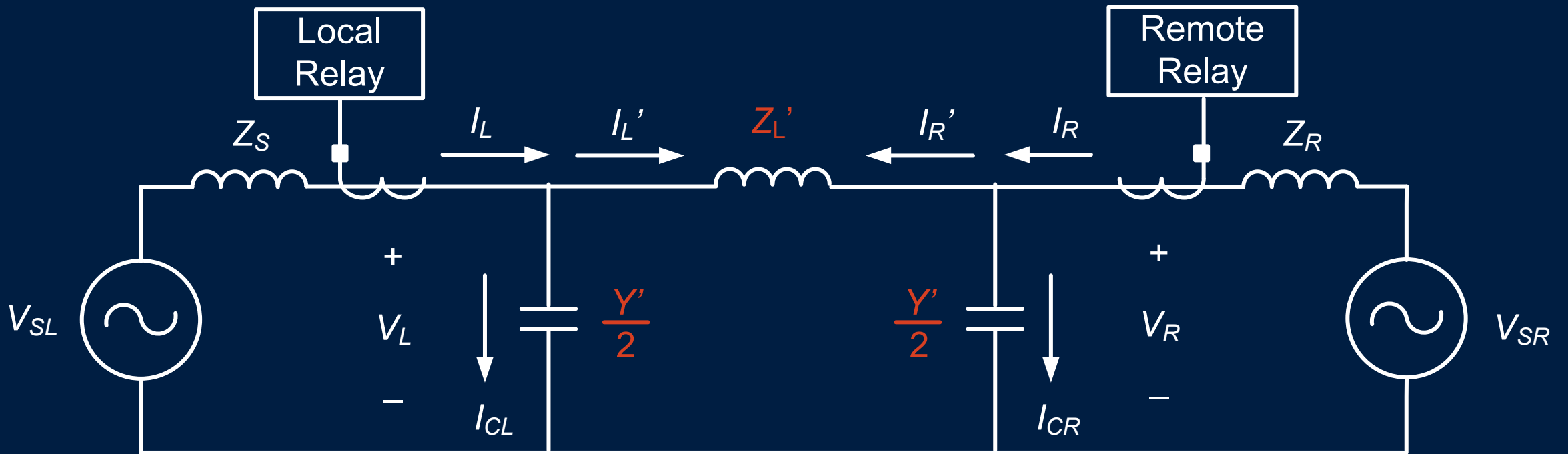
$$\angle I_{F_Est} = \angle(I_{2L}' + I_{2R}')$$



Examine Total Fault-Locating Error in the Takagi Method With π Line Model



Interpret the Takagi Method With π Long-Line Model

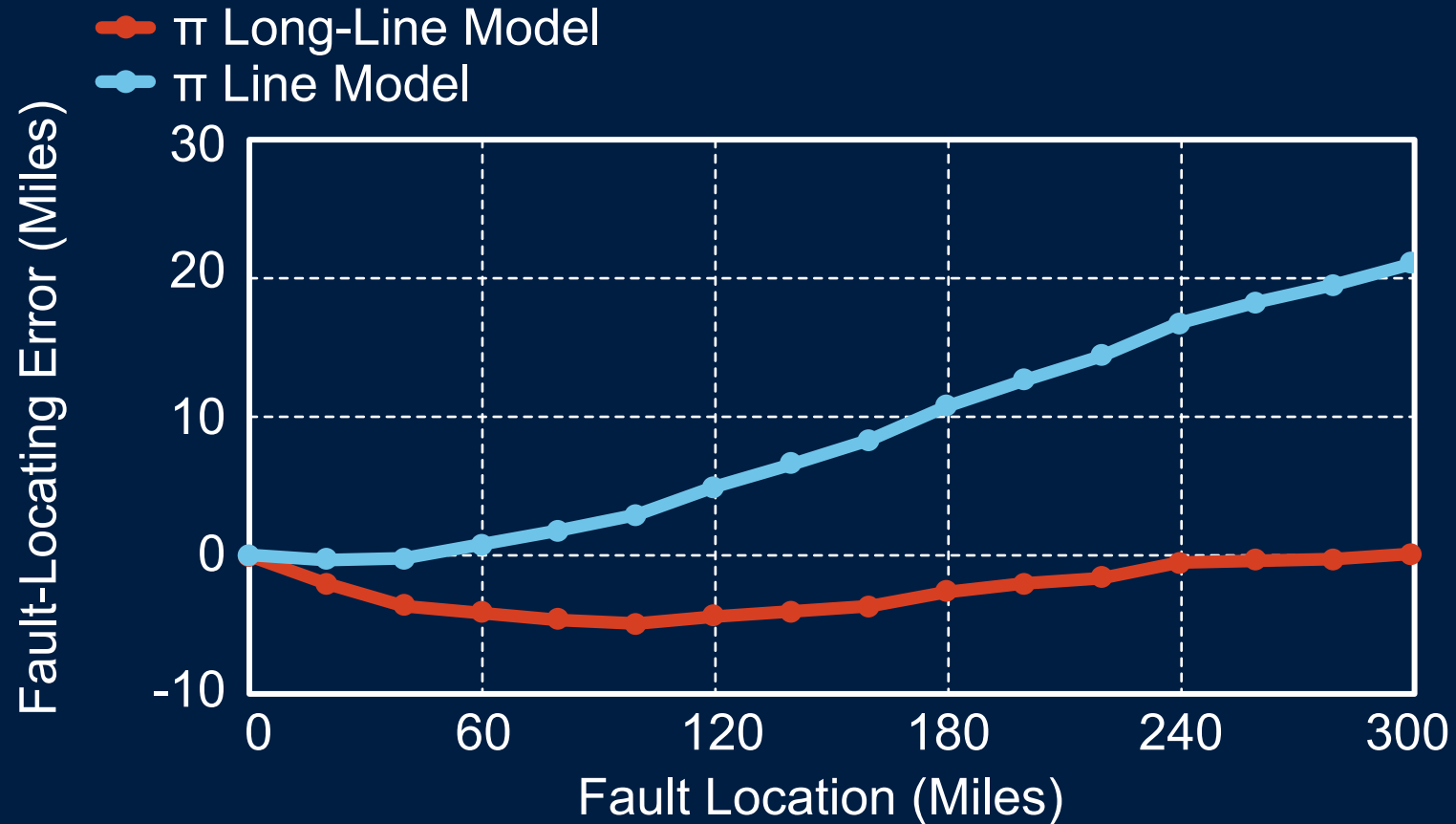


$$Z_L' = Z_L \left(\frac{\sinh \gamma l}{\gamma l} \right)$$

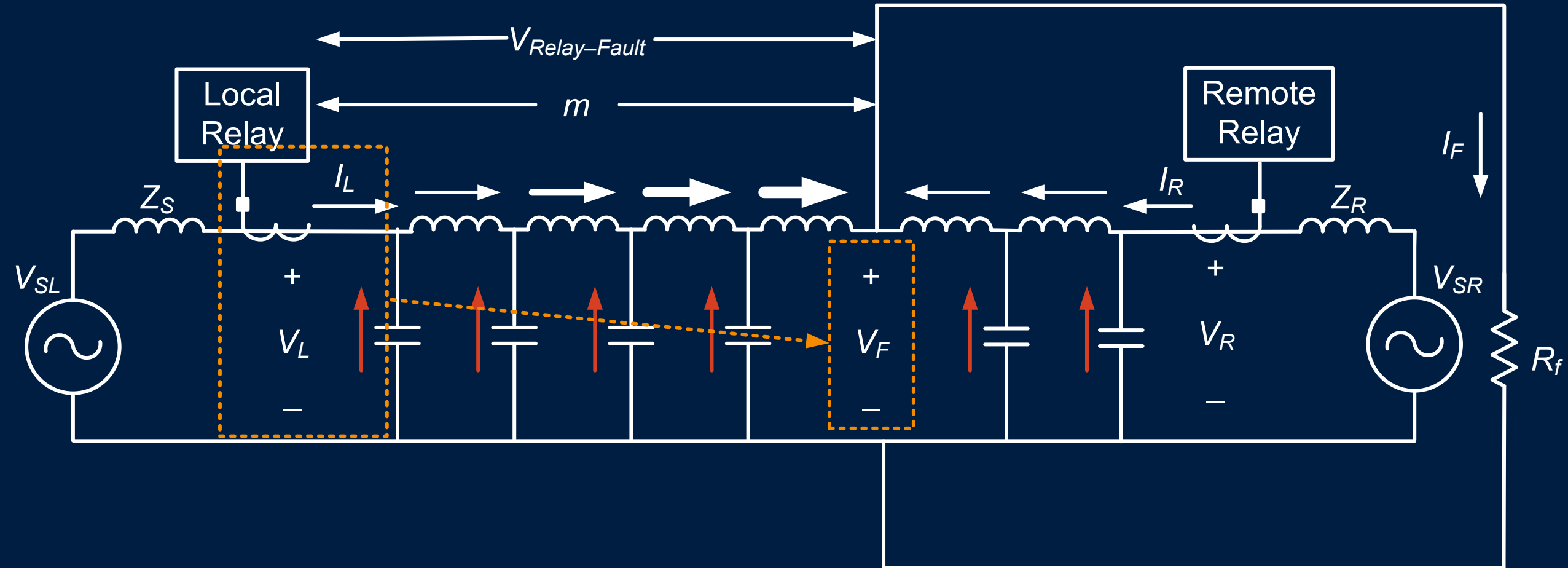
$\sim (0.93 - 1)$

new_length = $\sim (93 - 100)\%$ original_length

Examine the Total Fault-Locating Error in the Takagi Method With π Long-Line Model



Minimize $V_{\text{Relay-Fault}}$ Error in the Proposed Method With Distributed Line Model

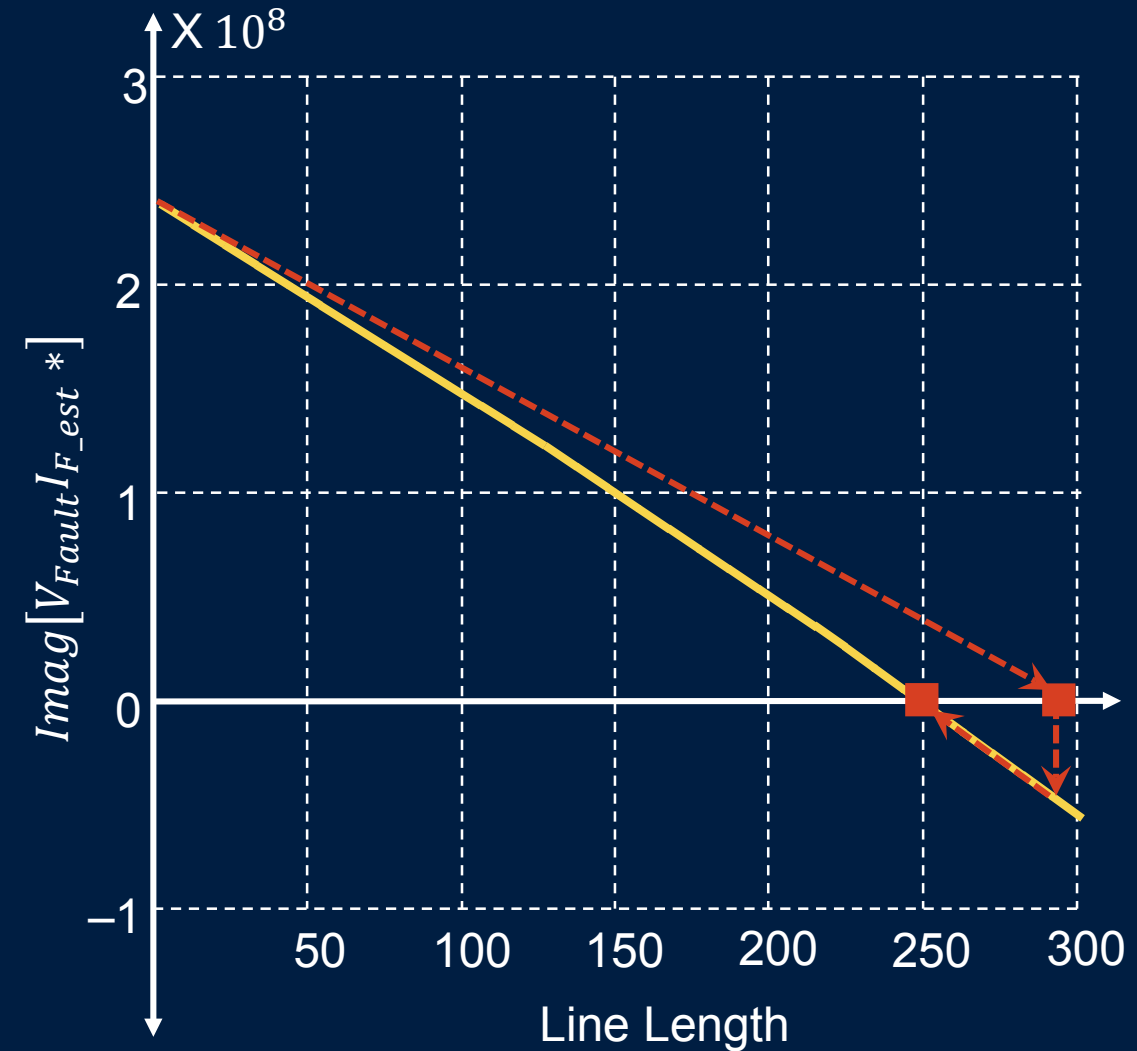
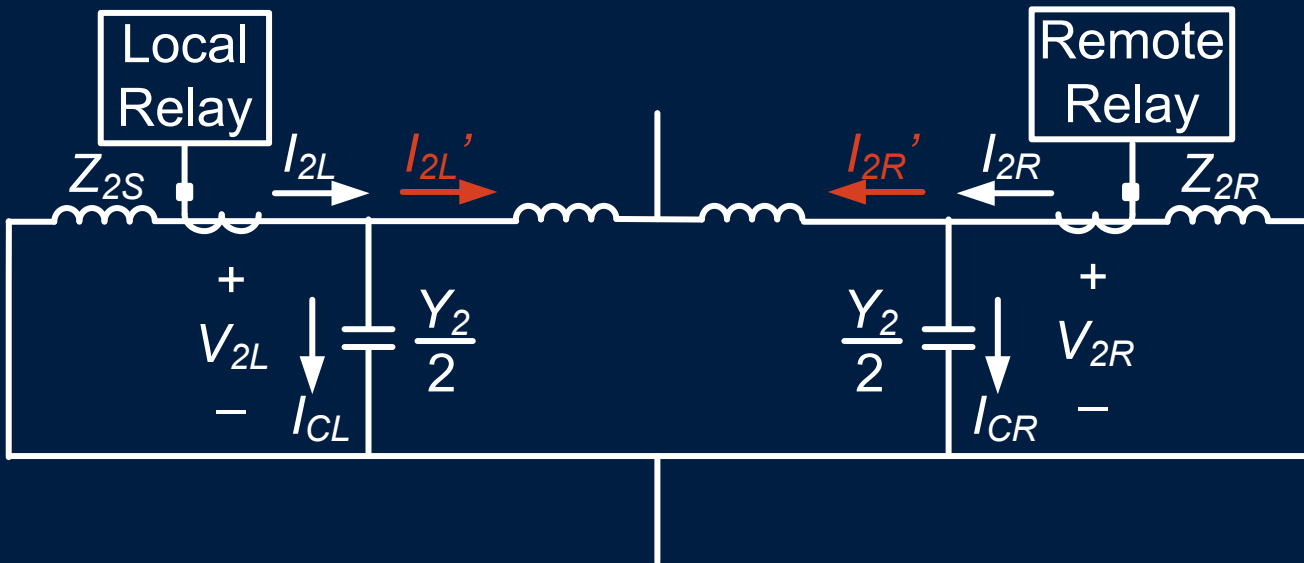


$$V_F = V_L \cosh(\gamma m) - I_L Z_C \sinh(\gamma m)$$

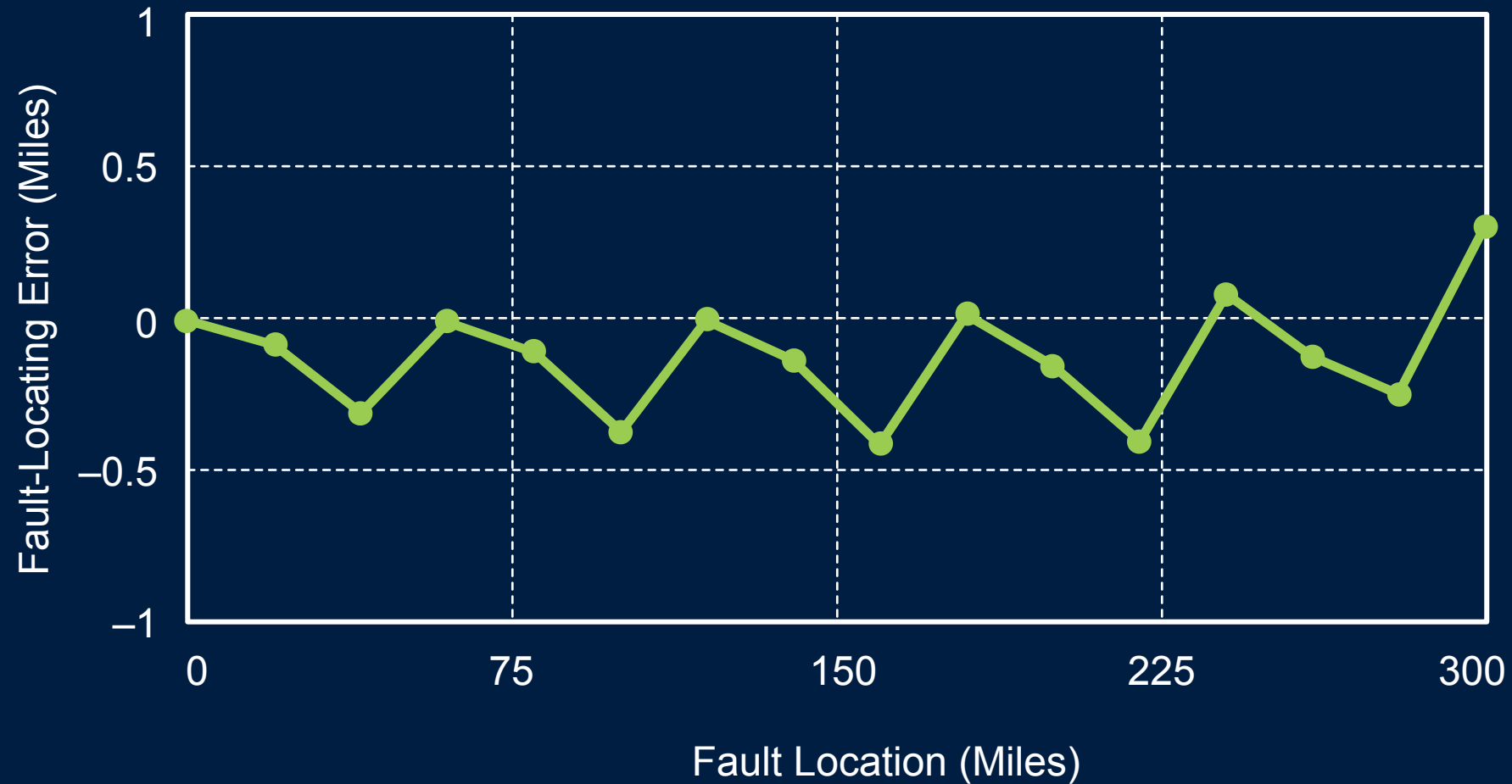
Fault-Locating Through the Use of the Proposed Method

$$V_{Fault} = I_F R_F$$

$$Imag[V_{Fault} I_{F_Est}^*] = Imag[I_F R_F I_{F_Est}^*]$$

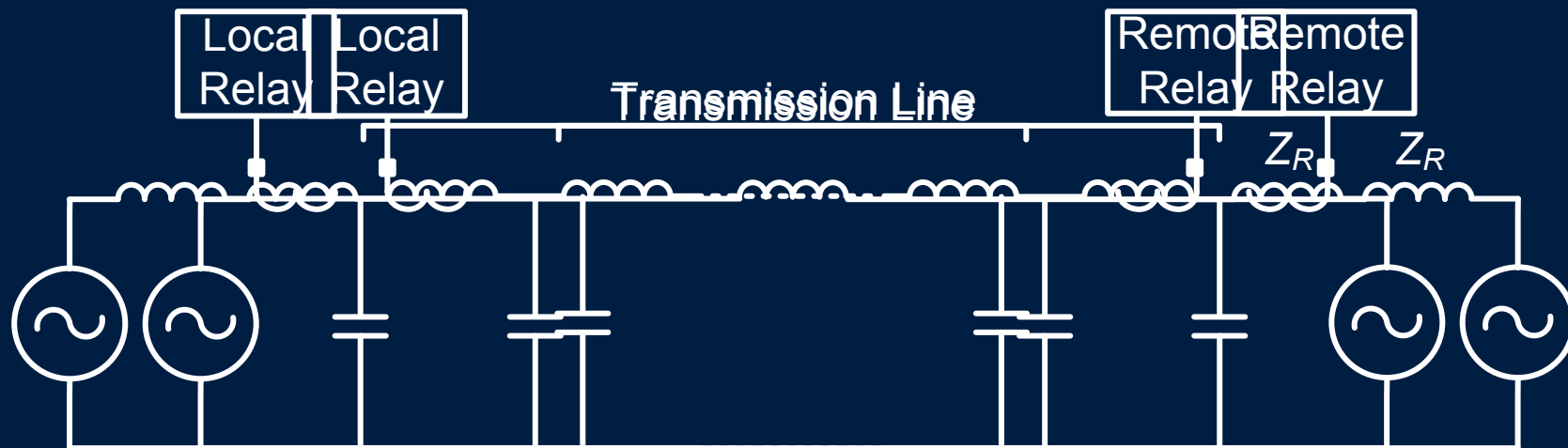


Examine the Total Fault-Locating Error in the Proposed Method

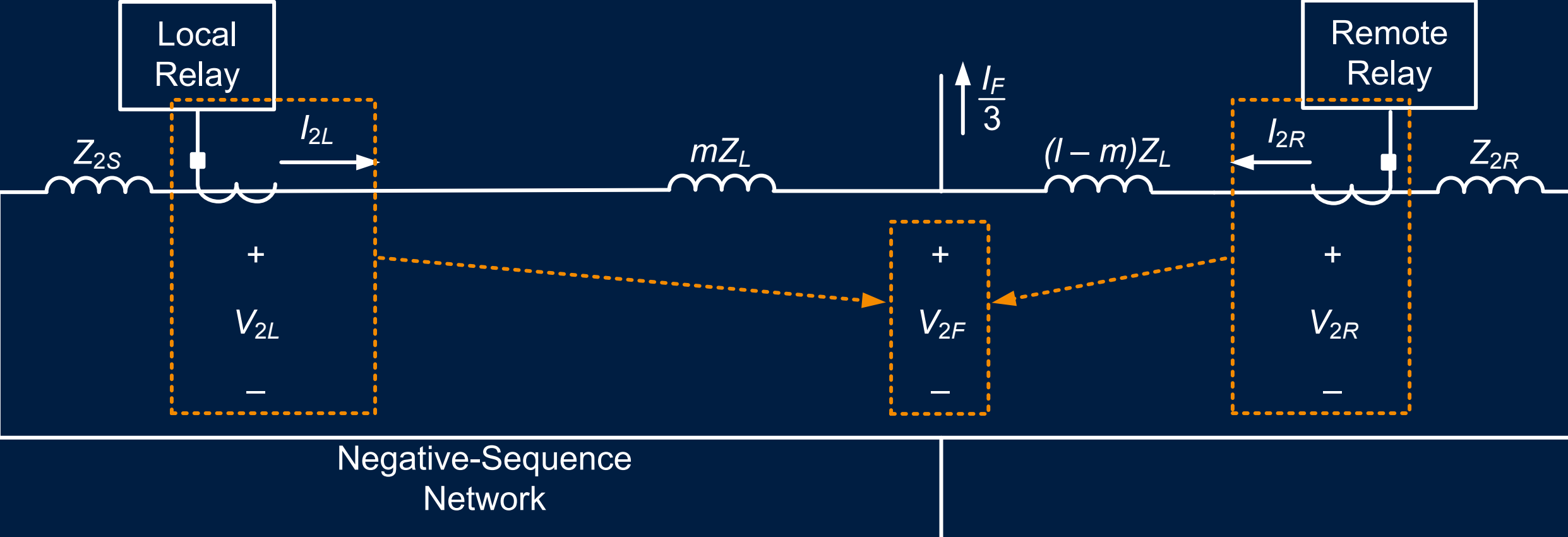


Evaluate Fault-Locating Methods With Local and Remote Currents and Voltages

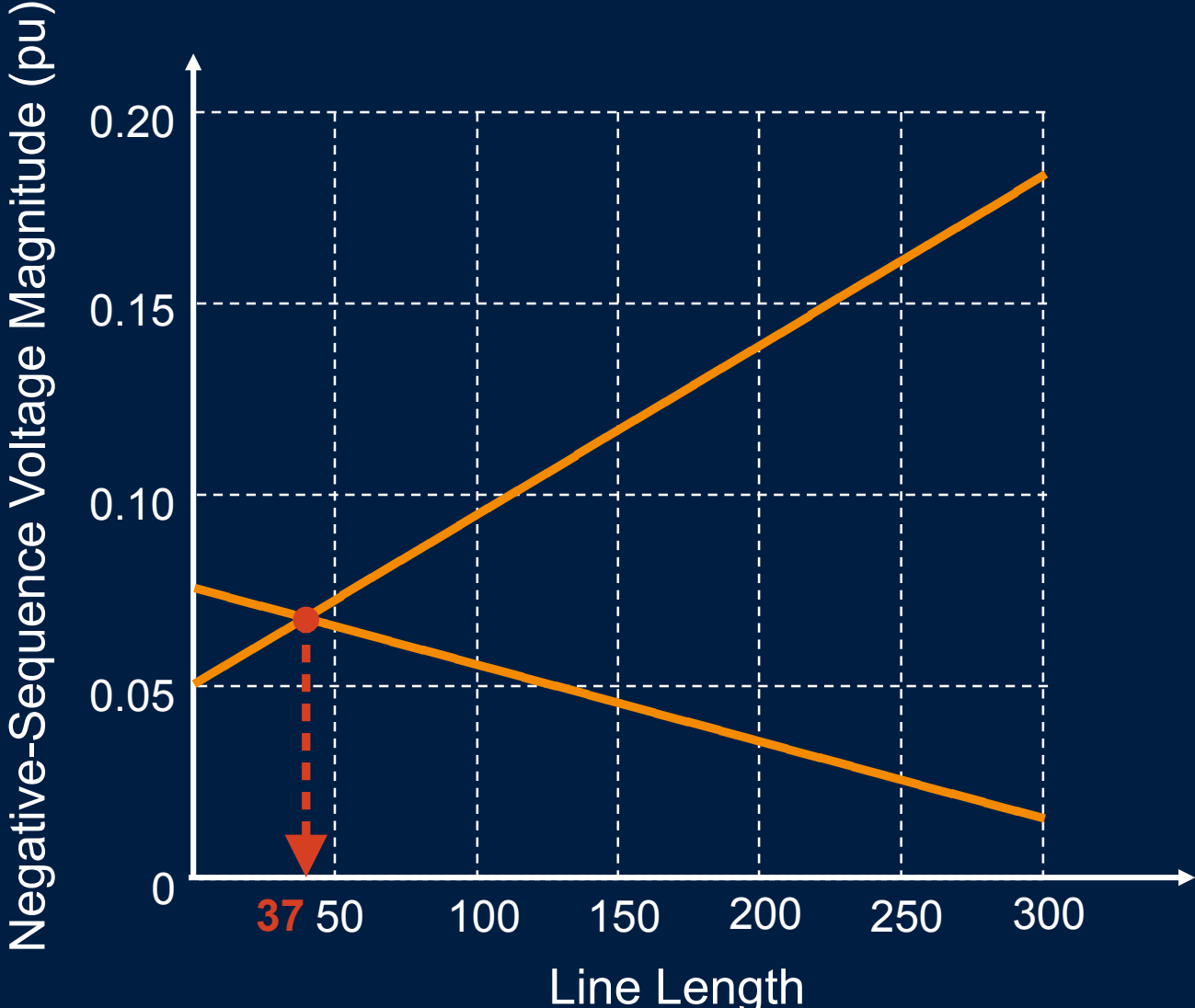
- Impedance-based method
- Proposed method (distributed line model)



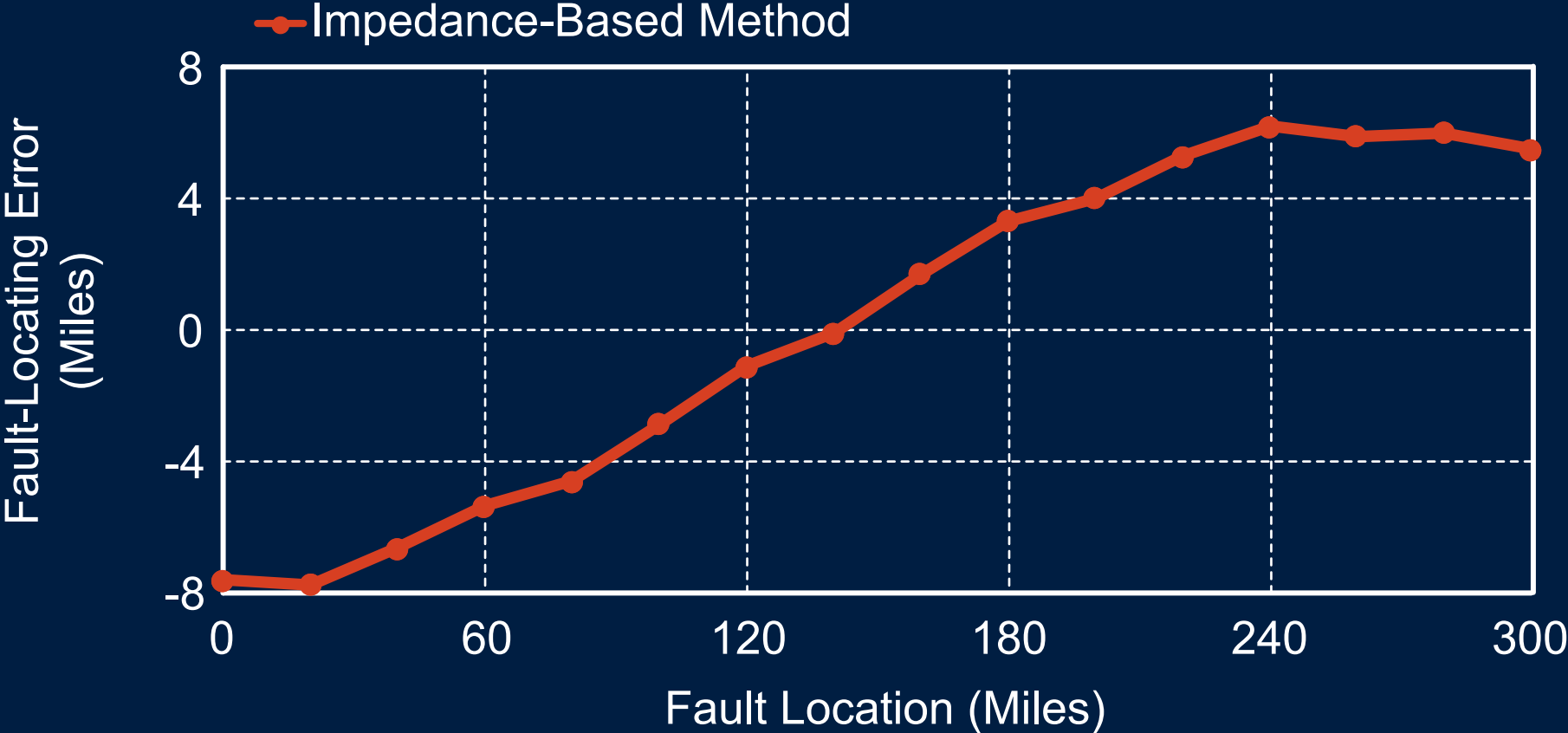
Interpret the Impedance-Based Method With Remote Currents and Voltages



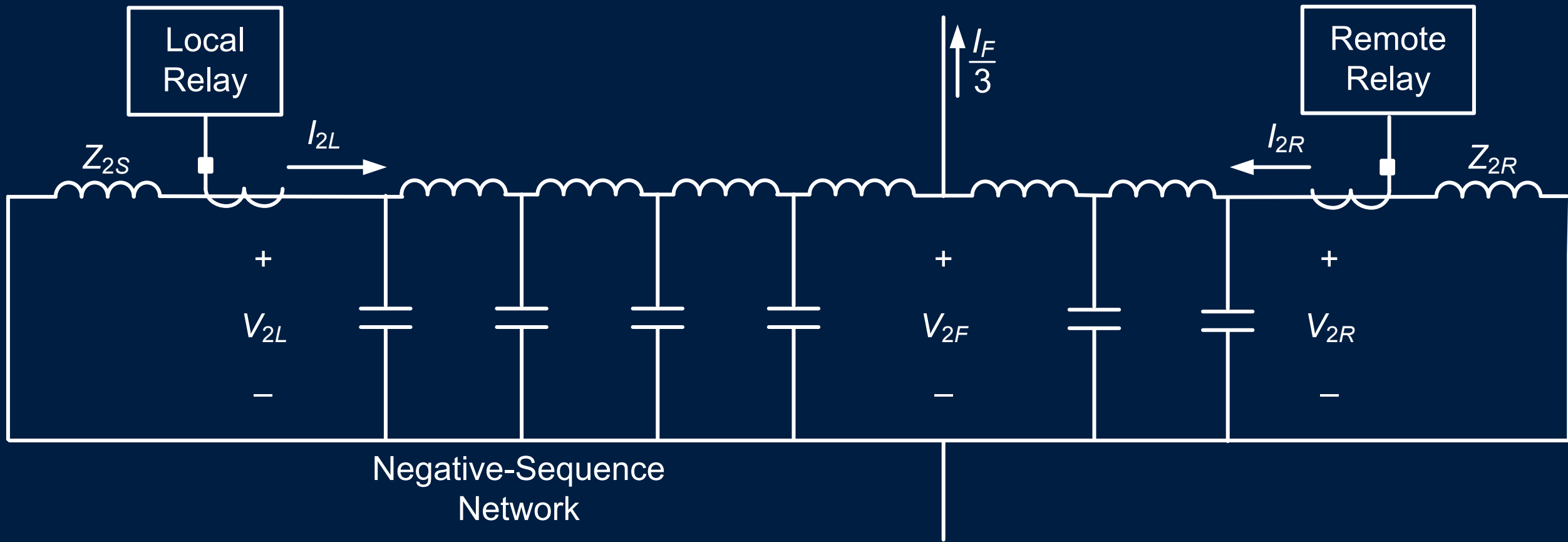
Examine the Impedance-Based Method For a Fault at 30 Miles



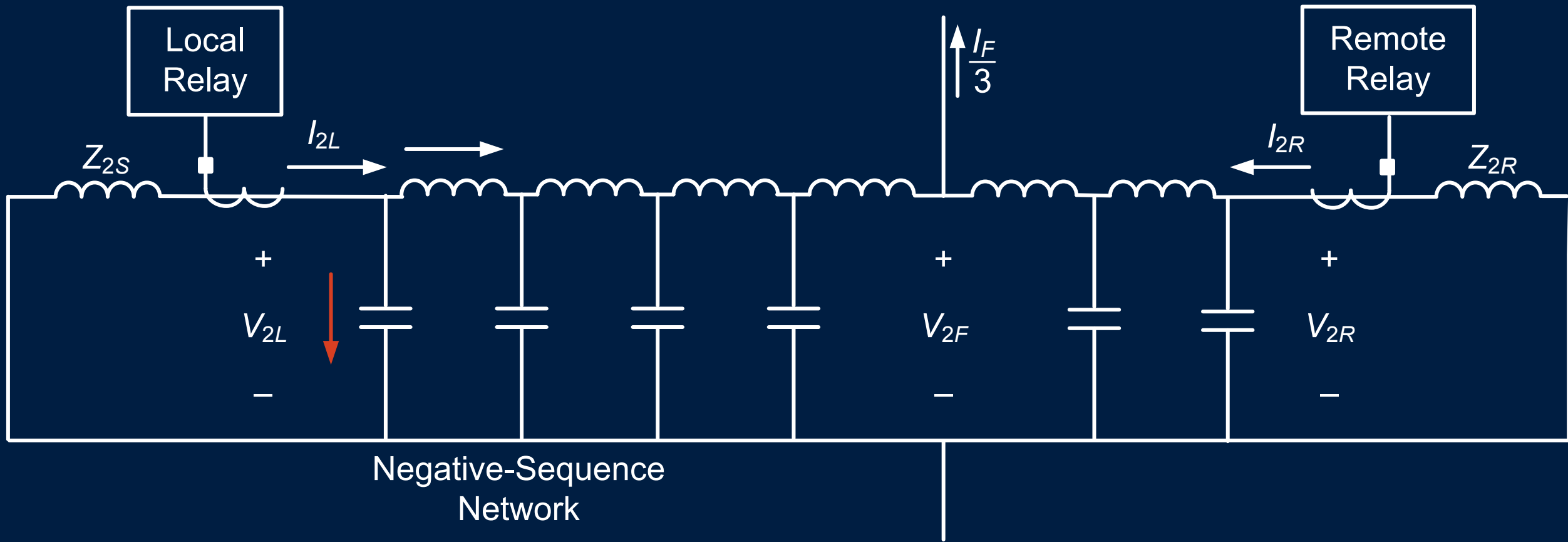
Examine the Total Fault-Locating Error in the Impedance-Based Method



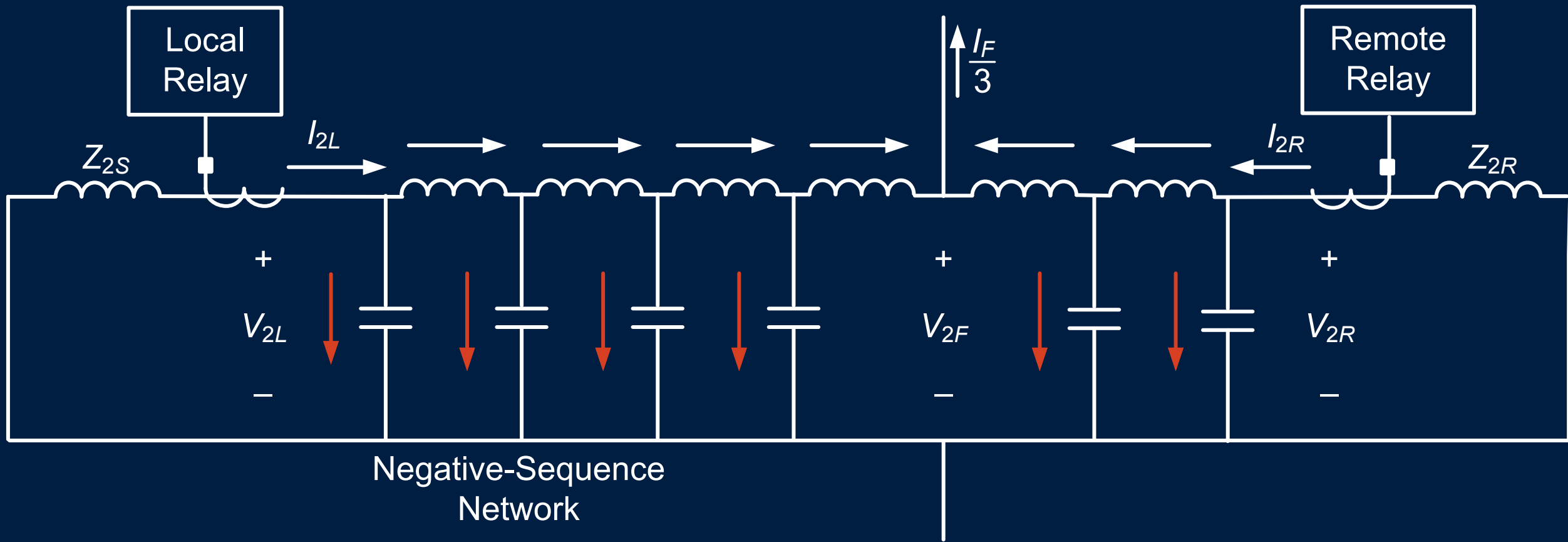
Investigate the Cause of Fault-Locating Error in the Impedance-Based Method



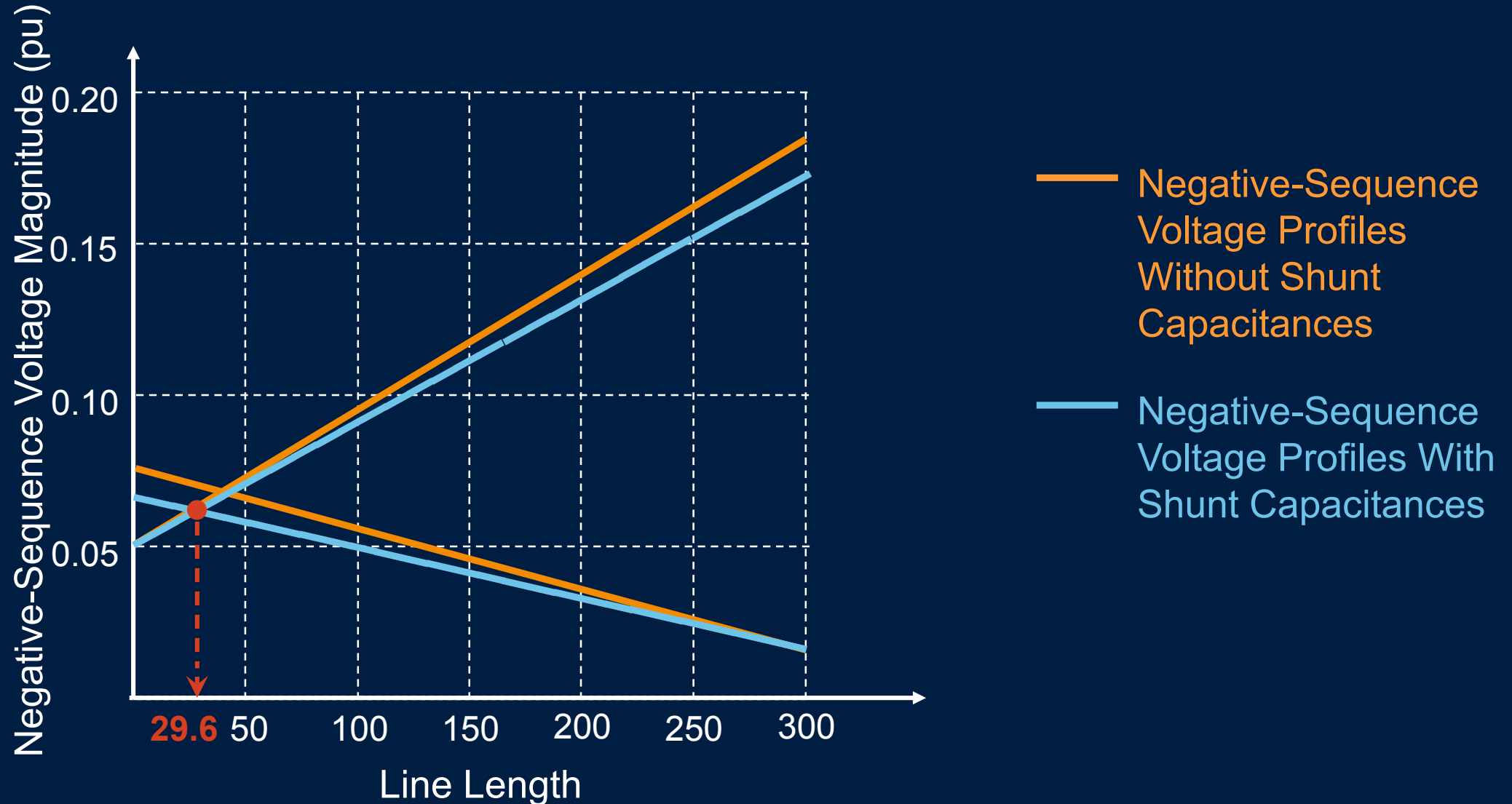
Investigate the Cause of Fault-Locating Error in the Impedance-Based Method



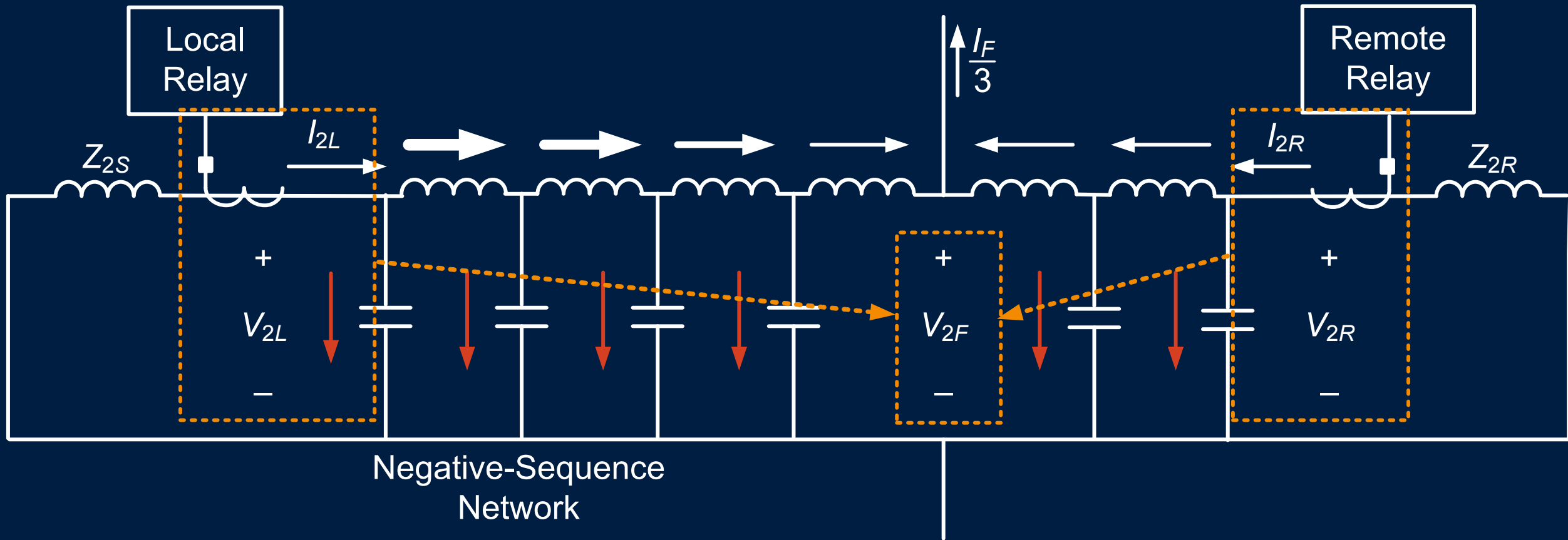
Investigate the Cause of Fault-Locating Error in the Impedance-Based Method



Rectify Fault-Locating Error in the Impedance-Based Method



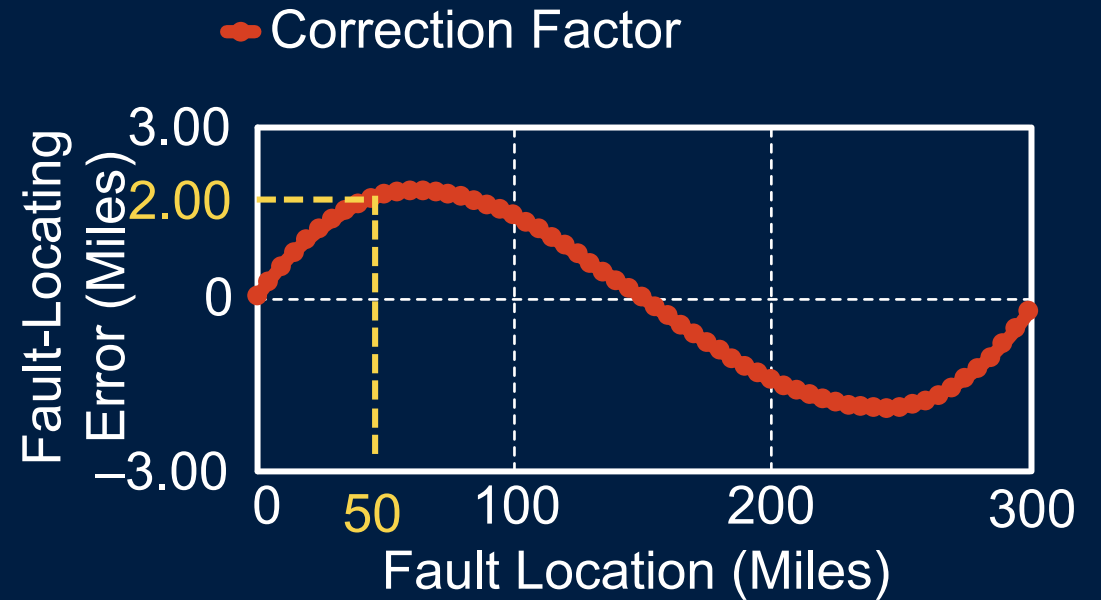
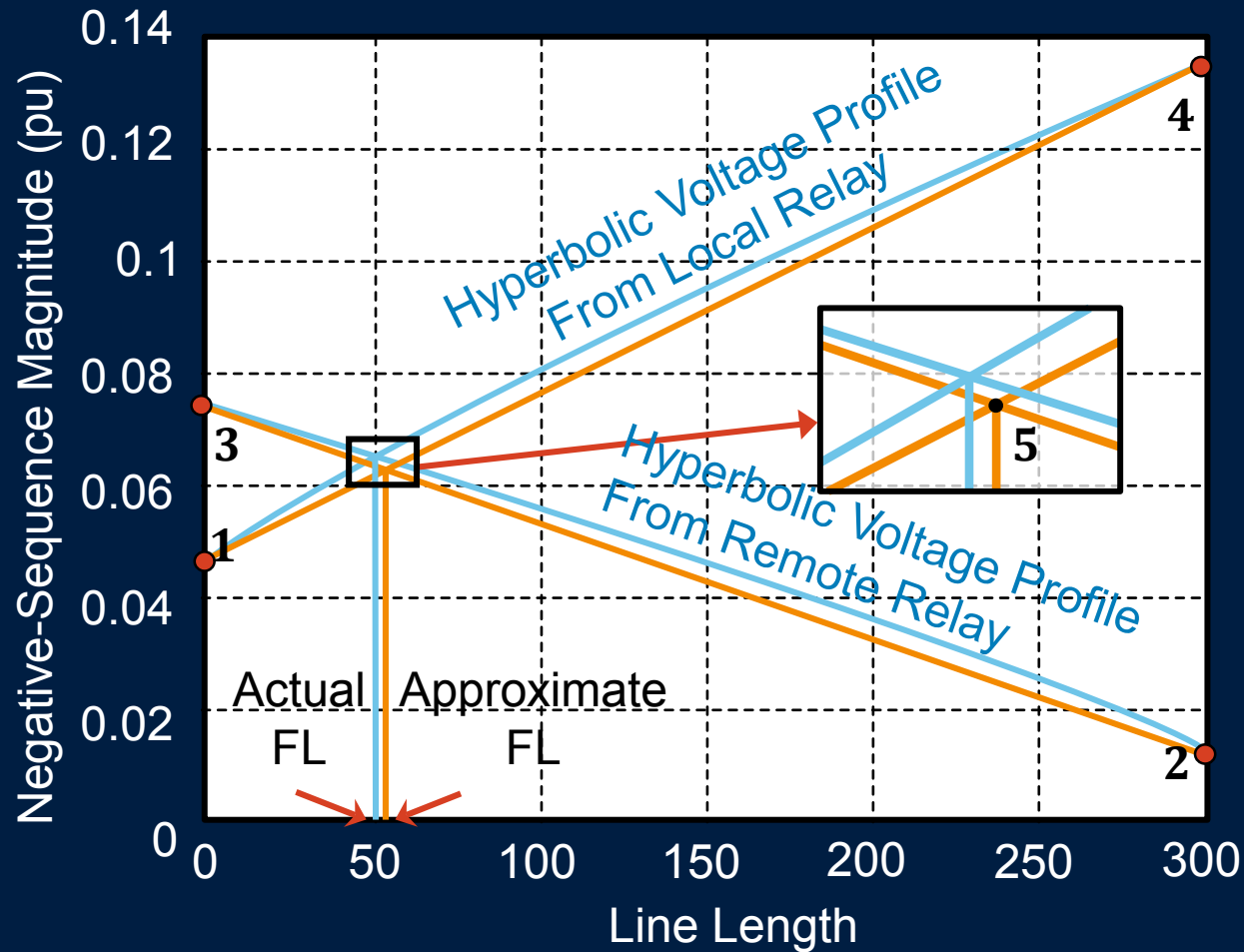
Evaluate the Fault-Locating Method With Distributed Line Model



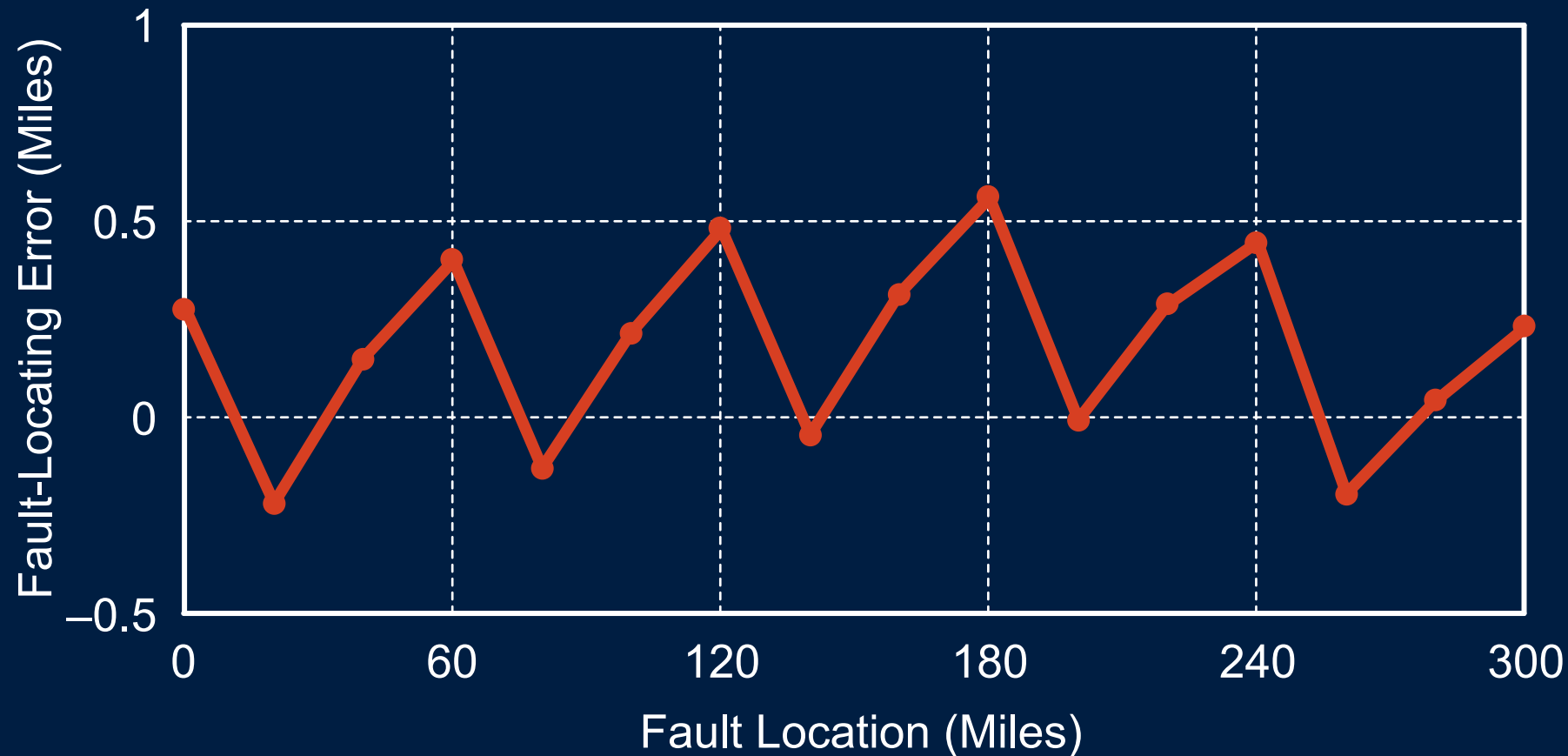
$$m = \frac{LL}{\gamma} * \tanh^{-1} \left[\frac{V_{2L} - V_{2R} \cosh(\gamma) + I_{2R} Z_c \sinh(\gamma)}{I_{2L} Z_c - V_{2R} \sinh(\gamma) + I_{2R} Z_c \cosh(\gamma)} \right]$$

$$\tanh^{-1} x = x + \frac{x^3}{3} + \frac{x^5}{5} + \frac{x^7}{7} + \frac{x^9}{9} + \frac{x^{11}}{11} \dots$$

Interpret the Computationally Efficient Fault-Locating Method



Examine the Total Fault-Locating Error in the Computationally Efficient Proposed Method



Review the Field-Event Results

Transmission Line Length: 190 Miles

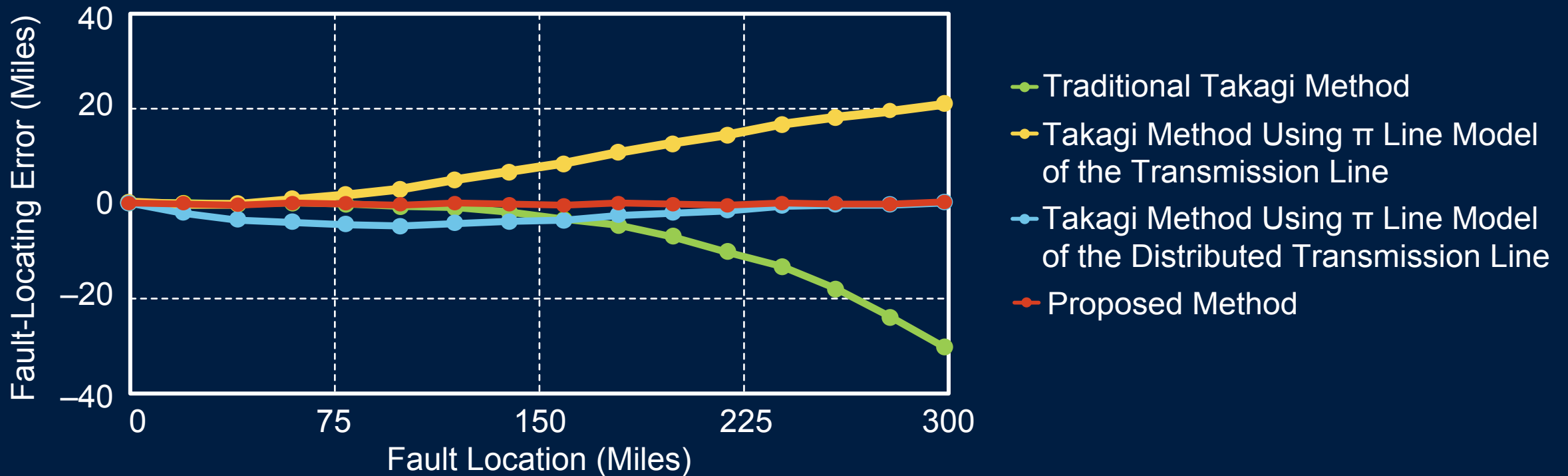
Traveling-Wave Fault Location: 130.6 Miles

Methods With Local CT/PT Measurements and Remote Currents	Fault Location (Miles)	Error (Miles)
Takagi method	132.0	-1.4
Takagi method with π line model	125.8	4.8
Takagi method with π long-line model	132.2	-1.6
Proposed method	130.8	0.2

Methods With CT/PT Measurements From Local and Remote Terminals	Fault Location (Miles)	Error (Miles)
Impedance-based method	129.6	1.0
Proposed method	130.2	0.4

Conclusions

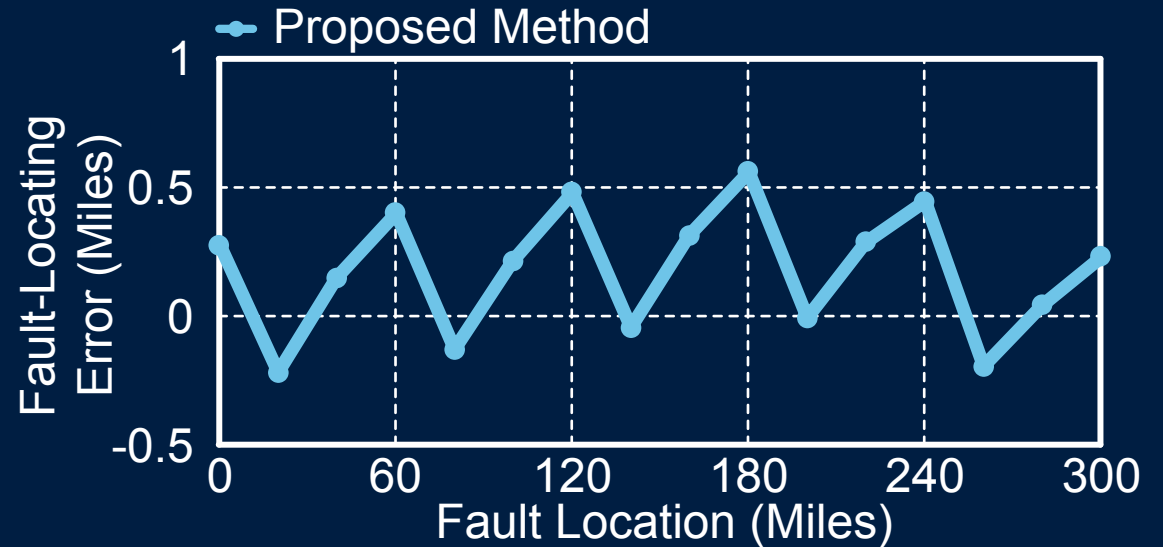
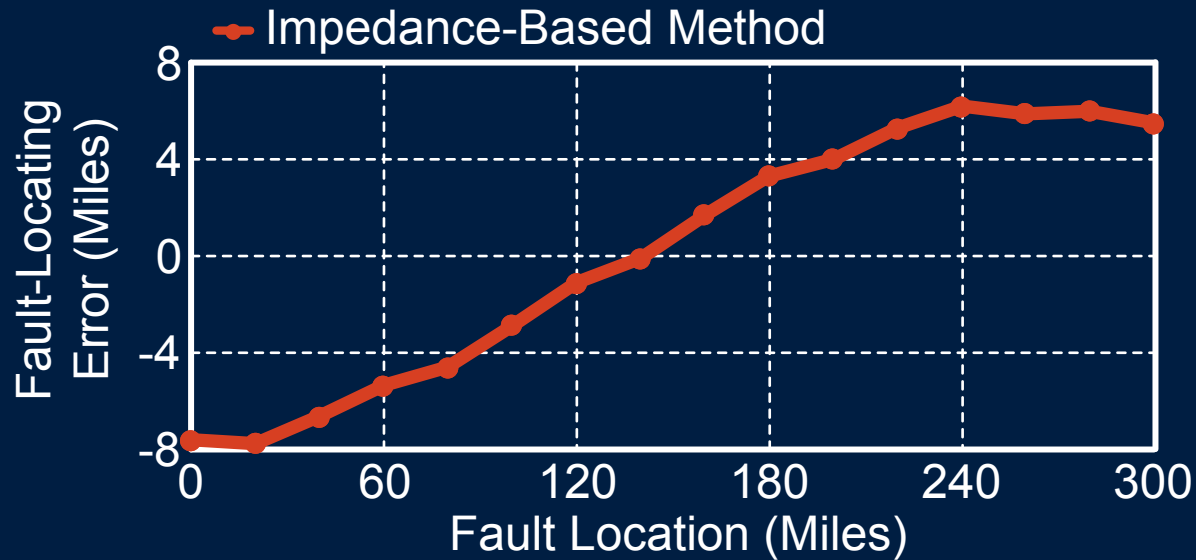
- Methods with local CT/PT measurements and remote currents only



- All methods based on zero-sequence impedance

Conclusions

- Methods with CT/PT measurements of local and remote terminals



- Fault-location estimation is affected by various parameters

Questions?