Very High-Resistance Fault on a 525 kV Transmission Line – Case Study

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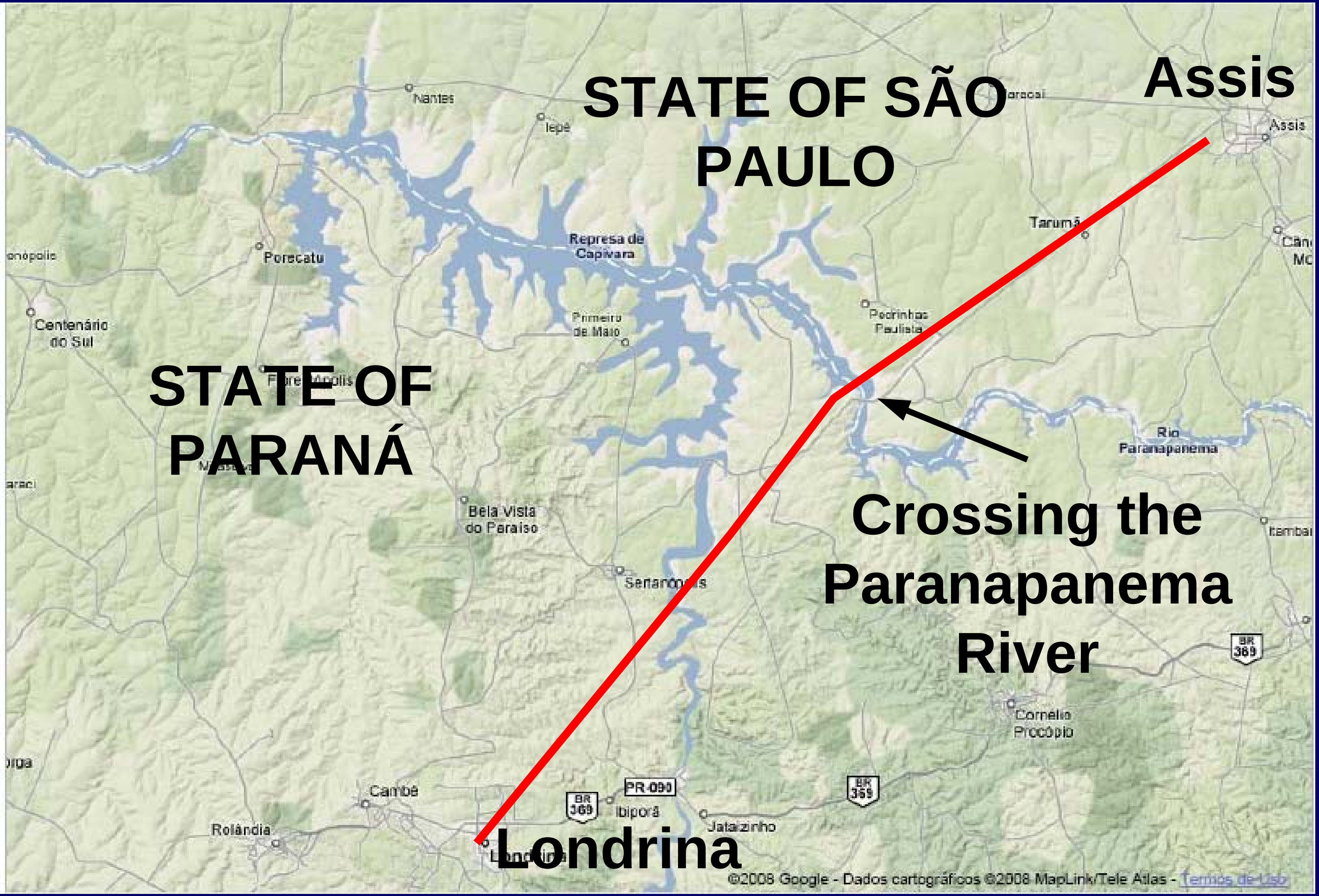
Objectives

- Present analysis of rare case of ground faults with very high fault resistance (R_F)
- Present event report analysis techniques using
  - Symmetrical components
  - Fault calculation program
- Evaluate and comment on protection functions

525 kV Transmission Line

One interconnection between south and southwestern regions of Brazil

Transmission Line



525 kV Transmission Line
Assis – Londrina

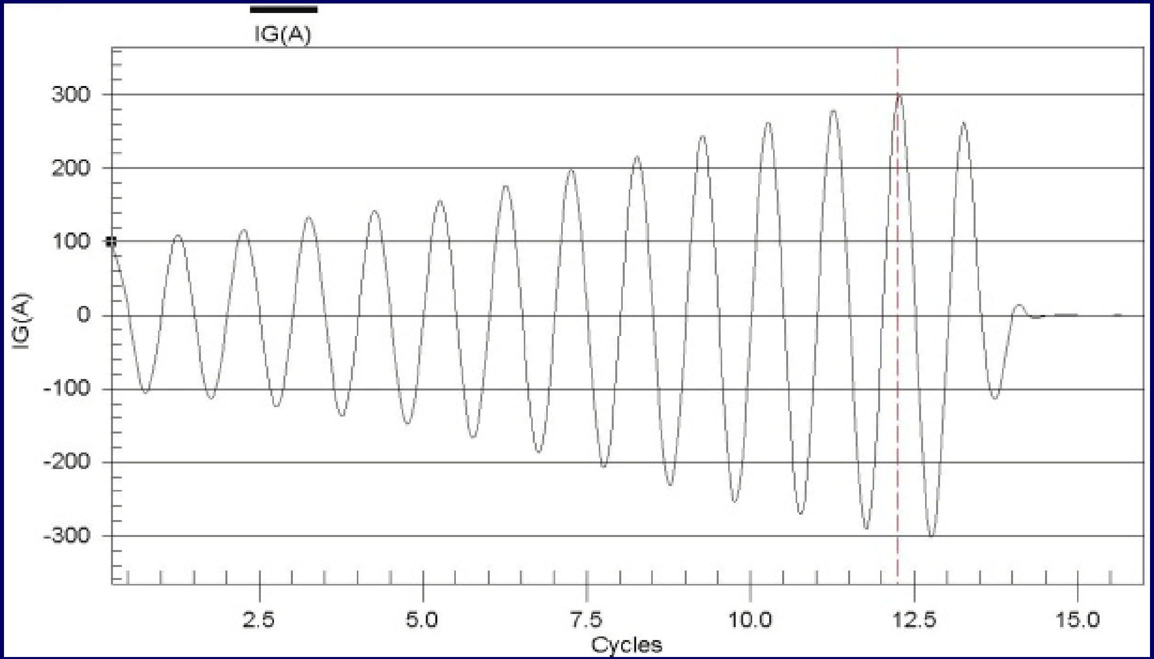
- Single circuit: 121.4 km (75 miles)
- $Z_{1L} = 2.5 + j\ 38.65$ ohms
- Line protection: two relays (redundant)
- Pilot schemes

July 2006 Events

- Three consecutive Phase B-to-ground faults: 12:36, 12:47, and 12:58 p.m.
- Correct performance of 67N and pilot scheme
- No condition for fault detection by distance function

First Fault

- Small ground currents at both extremities
- Gradual current increase
- Small fault angle (resistive)
- Total ground fault current = 566 A



Terminal A setting

67G1 = 240 A

First Approach for R_F

- For very high R_F, do not use Z_1, Z_2, Z_0

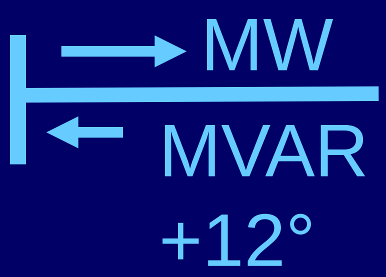
$$V/3 \cdot R_F = I0 \rightarrow V/R_F = 3 \cdot I0$$

$$R_F = \frac{525000/\sqrt{3}}{566} = 535\ \Omega$$

- 525 kV = approximate prefault line voltage
- 566 A = ground current at fault point

Terminal A Event Report Data

- Sending end
- No voltage drop

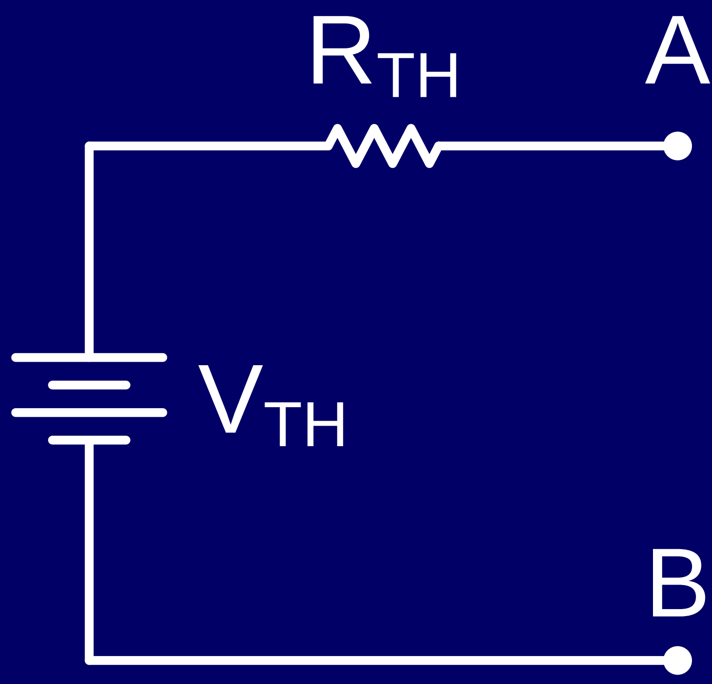


Prefault Currents	
	Magnitude (A)
I_{1A}	379.8
I_{1B}	379.8
I_{1C}	379.8

At Relay Trip Instant	
	Magnitude (A)
I_B	680.8
V_B	309.8
I_N	299.5

Calculation

Know Thèvenin's short-circuit current to compare measured and calculated values



Terminal A Sequence Using Thèvenin's Currents

	Magnitude (A)	Angle	
I_{2A}	109.50	–20.5	Event Report
I_{2B}	109.50	99.5	
I_{2C}	109.50	219.5	
I_{1A}			
I_{1B}	109.50	99.5	Adopted Equal to I_{2B}
I_{1C}			
I_{0A}	99.83	100.1	Event Report
I_{0B}	99.83	100.1	
I_{0C}	99.83	100.1	

Terminal A Fault Current

$$I_F \text{ Thèv} = I_{0B} + I_{1B} + I_{2B}$$

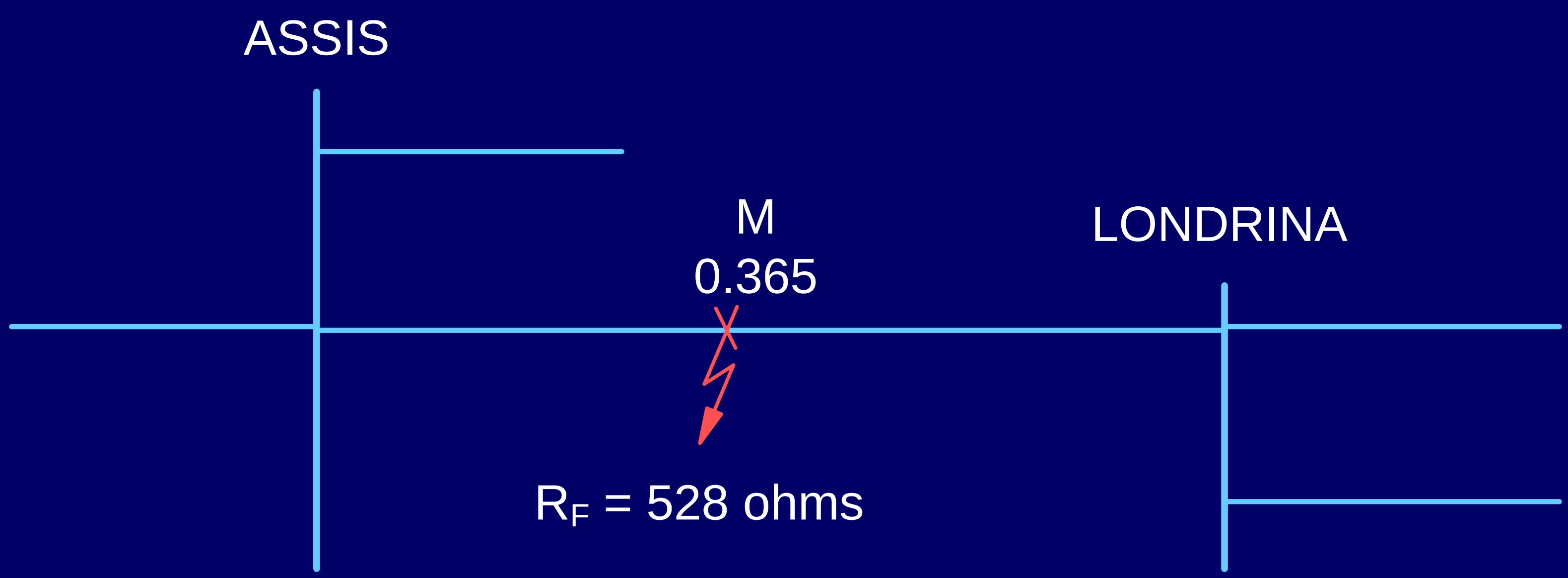
	Magnitude (A)	Angle
I_F Thèv (IB)	318.83	99.69
I Prefault	379.80	116.20
I_F Total	691.44	108.67
Event Report	680.80	112.20
		(1.54% Difference)

Terminal B Fault Current

$$\text{Thèv } I_B = I_{0B} + I_{1B} + I_{2B}$$

	Magnitude (A)	Angle
I_F Thèv (IB)	247.97	110.26
I Prefault	370.00	–85.30
I_F Total	147.04	–112.20
Event Report	146.30	–103.00
		(0.50% Difference)

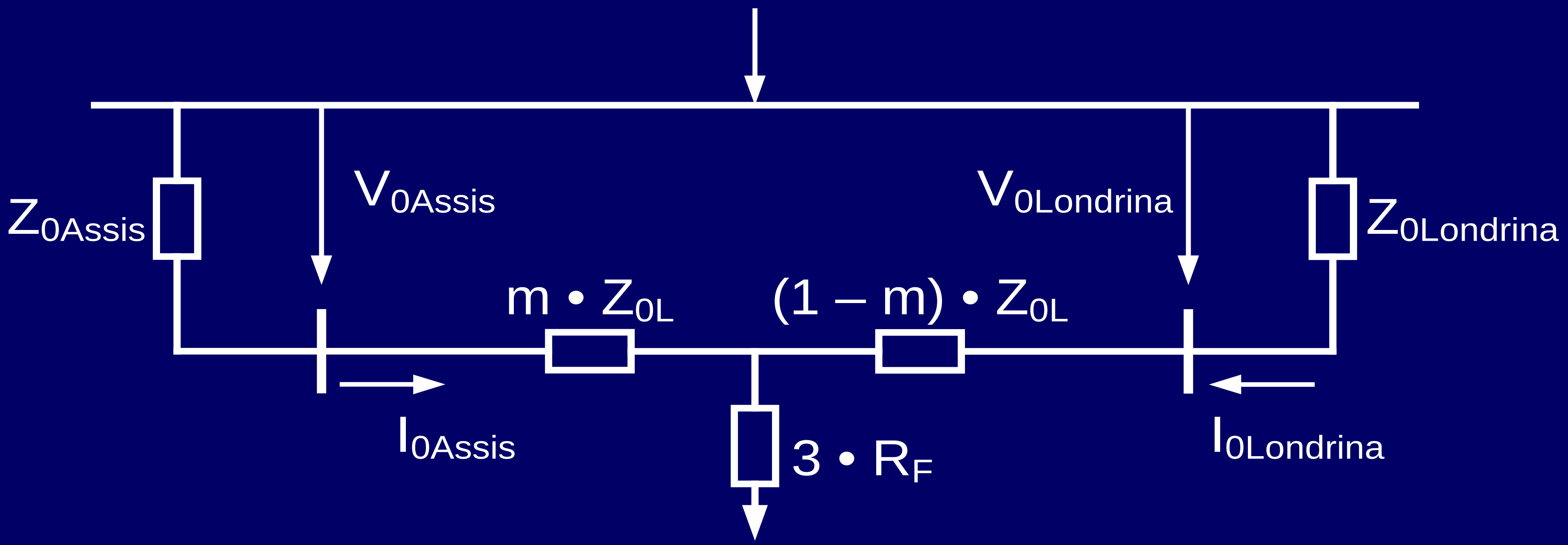
Short-Circuit Program



	Terminal A		Terminal B	
A	Event Report	Calculation	Event Report	Calculation
I_B (A)	318.80	294.70	247.97	271.90
I_{ground} (A)	299.50	299.10	266.90	267.50

Zero-Sequence Network

Calculated vs. Event Report



Zero-Sequence Network Comparison

	Event Report	**Calculation Program**
V_{0Assis} (V)	6100.0	6289.0
I_{0Assis} (A)	299.5	299.1
Z_{0Assis} (Ω)	61.1	63.0
$V_{0Londrina}$ (V)	2700.0	2710.0
$I_{0Londrina}$ (A)	266.9	267.5
$Z_{0Londrina}$ (Ω)	30.35	30.40

Calculated Apparent Impedance

Phase B

$$Z_B = \frac{V_B}{I_B + k_0 \bullet I_N}$$

V_B = B-phase voltage

I_B = B-phase current

I_N = ground current (3 • I0)

k_0 = ground factor

Terminal A Calculated Apparent Impedance

Calculated	Magnitude (A)	Angle
V_B (kV)	309.80	110.00
I_B (A)	680.80	112.20
I_N (A)	299.50	100.10
k_0	1.189	–13.90
$k_0 \bullet I_N$	356.11	86.20
$I_B + k_0 \bullet I_N$	1013.00	103.30
Z_B (Ω)	305.83	6.66

Terminal A Calculated Apparent Impedance – No Prefault Influence

No Load	Magnitude (A)	Angle
V_B (kV)	309.80	110.00
I_B Thèv (A)	318.83	99.69
I_N (A)	299.50	100.10
k_0	1.189	–13.90
$k_0 \bullet I_N$	356.11	86.20
$I_B + k_0 \bullet I_N$	670.29	92.58
Z_B (Ω)	462.19	17.42

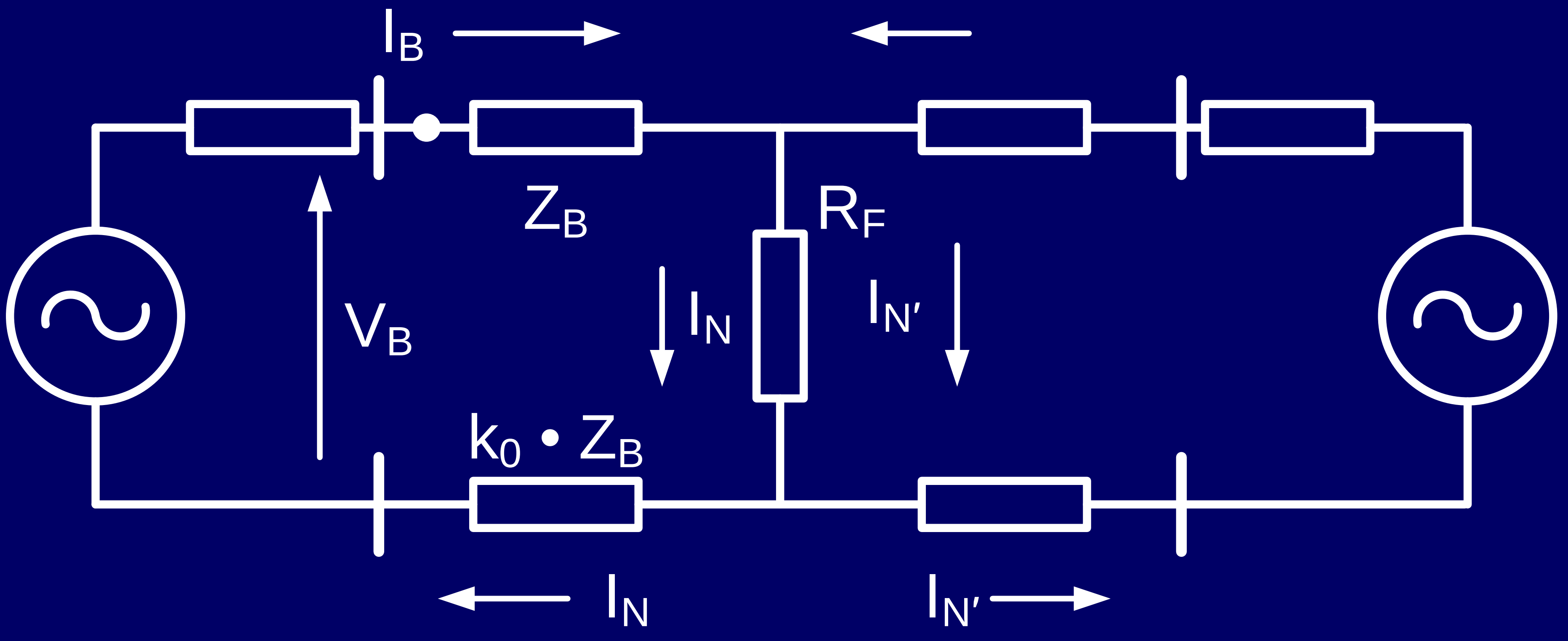
Terminal B Measured and Calculated Impedances

Measured	Magnitude (A)	Angle
Z_B (Ω)	1670.01	1.29

No Load	Magnitude (A)	Angle
Z_B (Ω)	552.58	10.27

Phase-to-Ground Impedance Expression

Using basic expression and considering R_F influence, derive expression from ground loop



Phase-to-Ground Impedance Expression

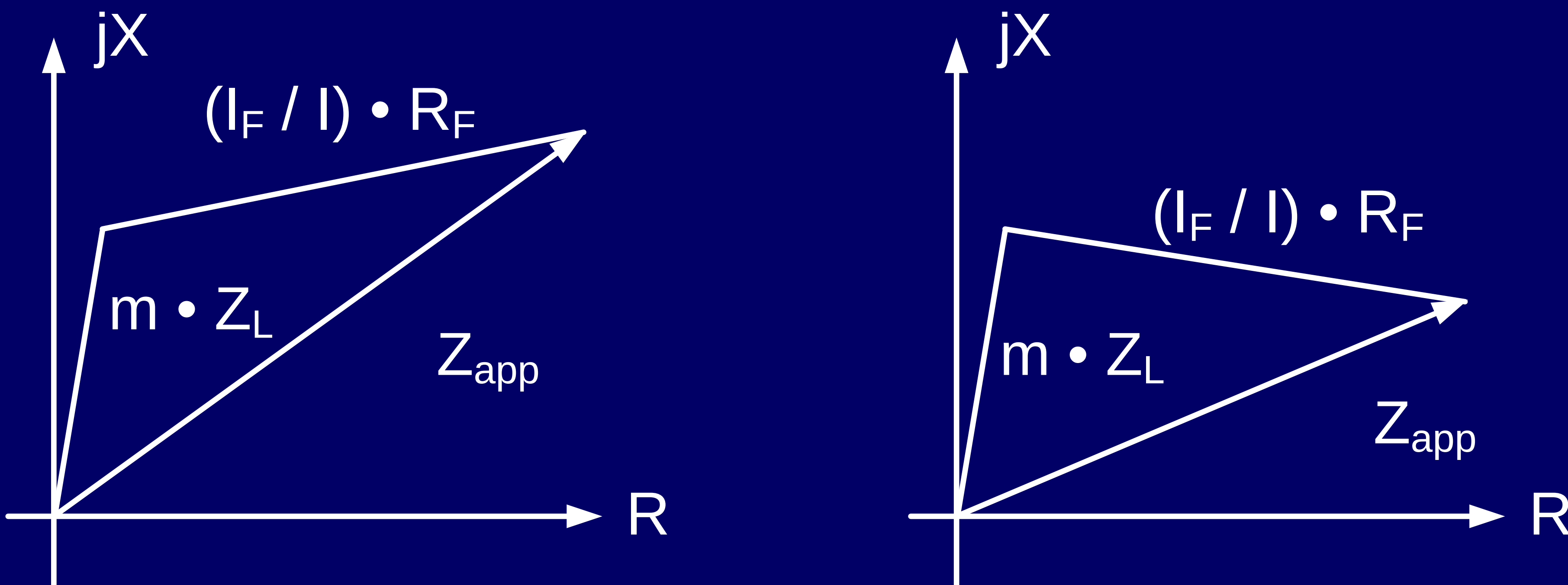
Z_B:

$$\frac{V_B}{I_B + k_0 \bullet I_N} = Z_B + \left(\frac{I_N + I_{N'}}{I_B + k_0 \bullet I_N} \right) \bullet R_F$$

Radial line:

$$\frac{V_B}{I_B + k_0 \bullet I_N} = Z_B + \frac{R_F}{1 + k_0}$$

Phase-to-Ground Impedance Expression



Z_L = line impedance

m = fault point

$I_N = 3 \bullet I0$ at Terminal A

$I_{N'} = 3 \bullet I0$ at Terminal B

$I_F = I_N + I_{N'}$

Impedance Comparison for R_F = 528 Ω

		Z Event Report	Z Calculated	Z Estimated by Expression
Terminal A Z_B (Ω)	No load	462.19	466.27	445
	Load	305.83	–	293
Terminal B Z_B (Ω)	No load	552.58	514.70	530
	Load	1670.01	–	1591

Phase-to-Ground Impedance Expression

If fault point (Z_B) is known,
R_F can be estimated by:

$$R_F = \frac{Z_{Bapp} - Z_B}{\dfrac{I_N + I_{N'}}{I_B + k_0 \bullet I_N}}$$

Second and Third Faults

$R_F = 342\ \Omega < 518\ \Omega$

$m = 0.365$

Z_{app} (Terminal A) = 227.25 Ω

Z_{app} (Terminal B) = 631.18 Ω

$R_F = 218\ \Omega < 342\ \Omega < 518\ \Omega$

$m = 0.352$

Z_{app} (Terminal A) = 159.28 Ω

Z_{app} (Terminal B) = 321.08 Ω

Primary Cause of Faults

Facts

- Estimated fault location:
  0.365 • 121.4 = 44.8 km from Terminal A
- Location on river crossing point
- Rainy and windy day with atmospheric electrical discharges

Primary Cause of Faults

Suppositions

- Flashover across insulator – NO
- Arc opening to water (intense winds and waves)
- Arc opening on tree

New Faults in August 2006

- Two consecutive Phase B-to-ground faults: 2:00 and 2:04 p.m.
- Correct performance of 67N DCUB pilot scheme
- Correct distance function performance for second fault

First Fault in August

$R_F = 350\ \Omega$

$m = 0.365$

$3 \bullet I0$ (Terminal A) = 446.9 A $\angle -10.4°$

$3 \bullet I0$ (Terminal B) = 440.9 A $\angle -6.3°$

Z_{app} (Terminal A) = 170.8 Ω

Z_{app} (Terminal B) = 1125.39 Ω

Primary Cause of Faults

At the time, line maintenance team coincidentally observed flashover from transmission line to vegetation close to Paranapanema River
crossing point

Second Fault

Classic phase-to-ground fault with high current and voltage drop

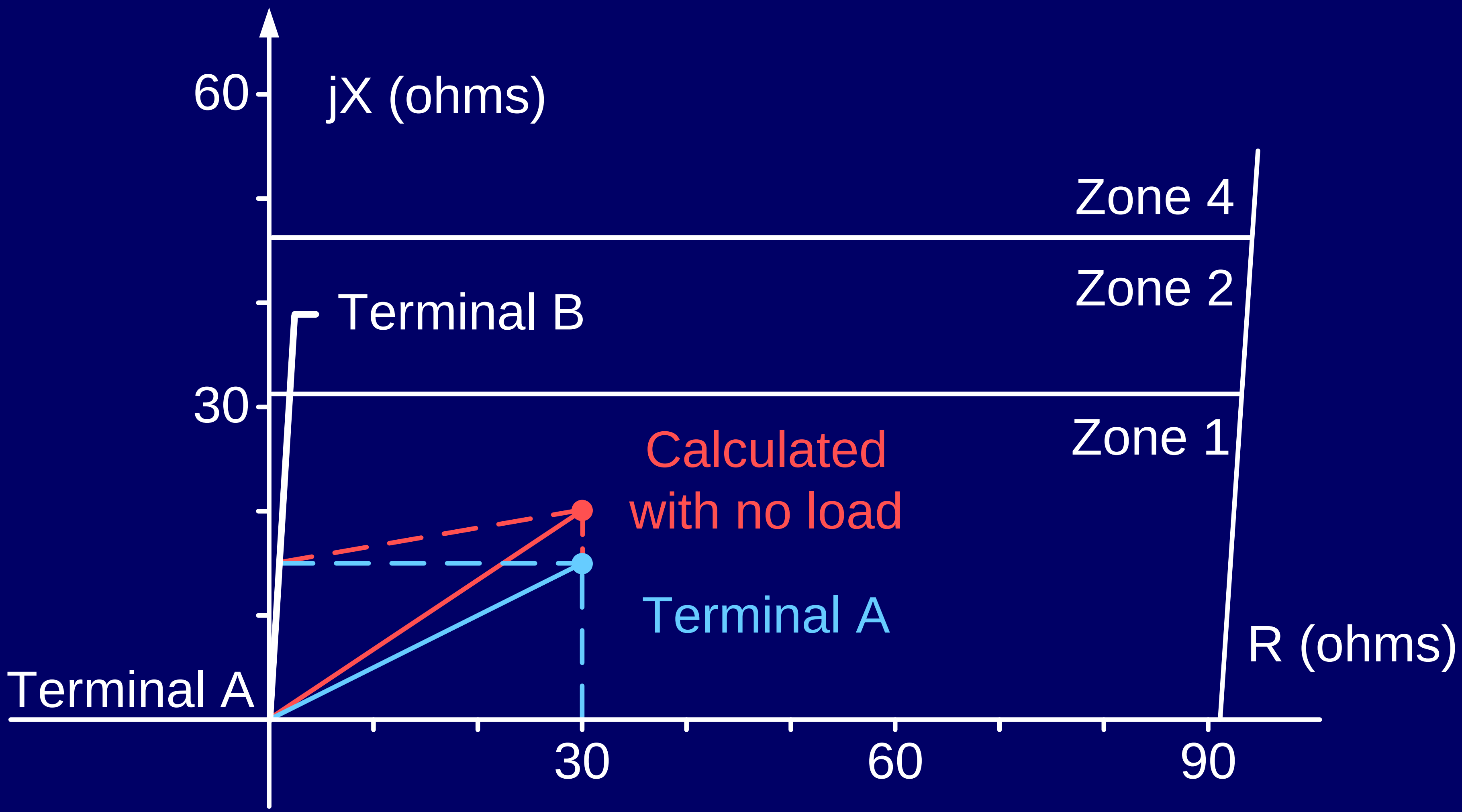
$R_F = 34\ \Omega$
$m = 0.359$

$3 \bullet I0$ (Terminal A) = 2914 A $\angle -23.3°$
$3 \bullet I0$ (Terminal B) = 2569 A $\angle -26.7°$

Z_{app} (Terminal A) = 32.87 Ω (Zone 1)
Z_{app} (Terminal B) = 51.91 Ω (Zone 2)

Second Fault

Measured at Terminal A

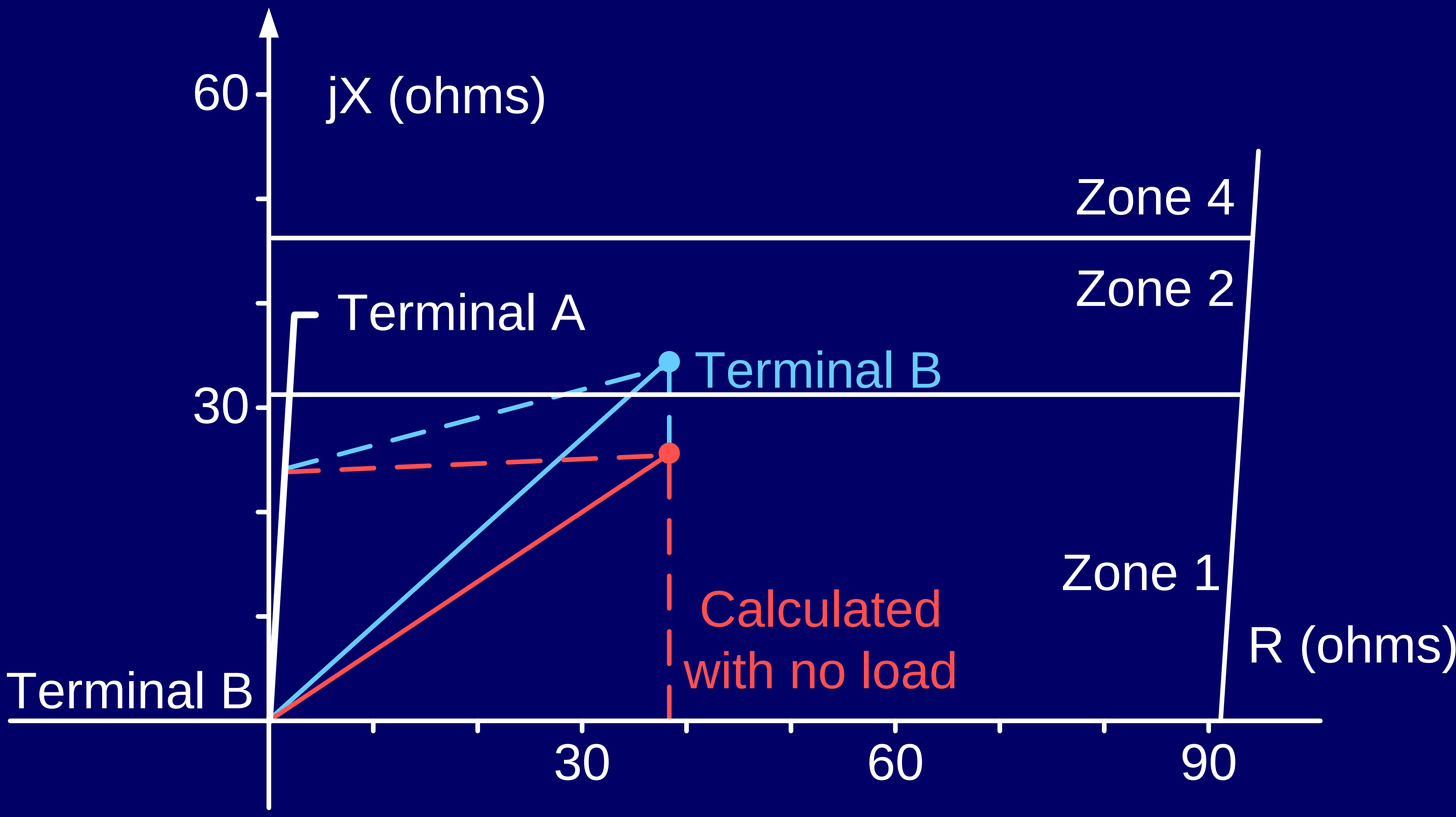


Fault at 44.8 km

Fault locator indication = 47 km

Second Fault

Measured at Terminal B



Fault at 78 km

Fault locator indication = 76.9 km

Differential Element

- An alternative to main protection
- As sensitive as ground overcurrent function
- Does not require voltage information
- Immune to mutual coupling effect

Resistive Reach Setting Criteria

- Based on expected R_F magnitudes
- R_F values can be very high for any level of line voltage
- Manufacturers’ documented recommendations need to be considered

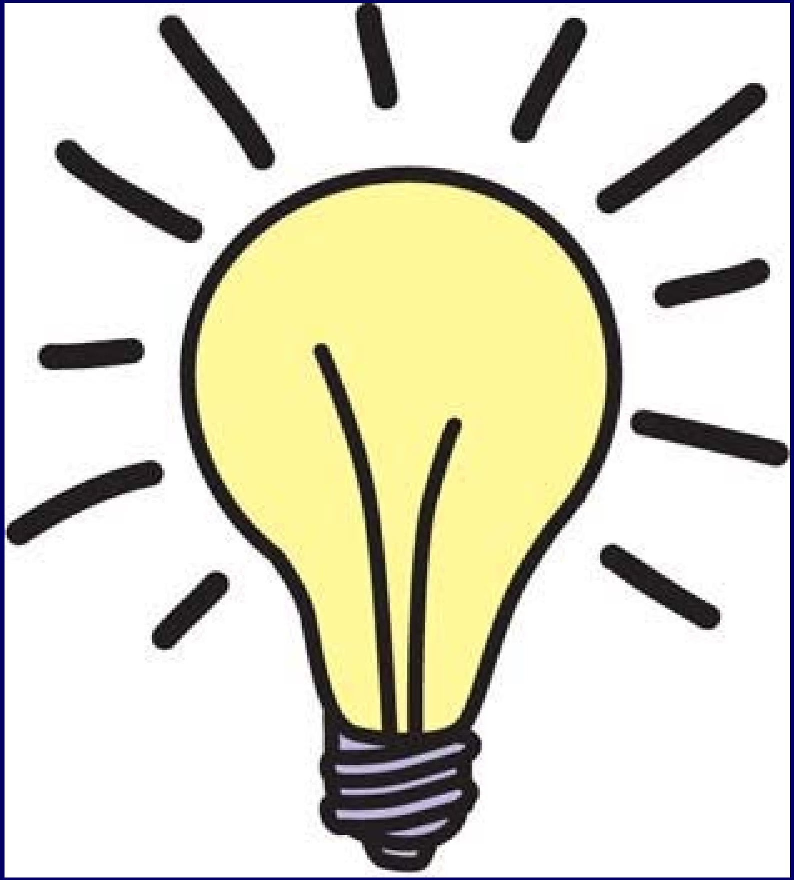
Conclusions

Events

- 67N DCUB pilot scheme had reliable performance
- Concepts and algorithms applied to directional discrimination and phase selection increase line protection reliability
- Negative-sequence fault location algorithm is sufficiently accurate

Analysis Techniques

Basic tools and simple concepts produce good results



Fault Resistance

- R_F on order of hundreds of primary ohms are possible at all line voltages
- These faults are more frequent than believed

Transmission Line Protection for High-Resistance Faults

Evaluate use of differential function for:

- Nonradial long lines
- Any voltage level with reliable communication