CONNECTIONS SUMMIT

# Protection and Coordination for Solar Sites on the Distribution Power System

Luke P. Booth
Application Engineer – Protection
Schweitzer Engineering Labs, Inc.

ELECTRICITIES of NORTH CAROLINA, INC.

# Overview

- The Impacts of DG on feeder protection and the need for communications assisted tripping schemes
- Direct Transfer Tripping (DTT) Communication Scheme
- Mirror Bits
- Direct Fiber Attributes

# DG Impact on Distribution Feeders

- Unintentional islanding
- Increased fault duty
- Relay desensitization
- Nuisance tripping
- Automatic reclosing

# Unintentional Islanding

- Occurs when portion of area EPS and DR become electrically isolated from rest of area EPS and DR continues to energize island
- Should be avoided for two major reasons
  - There is potential for negative effects on voltage, frequency, and power quality
  - Islanded generator complicates both automatic reclosing and manual switching

# Increased Fault Duty

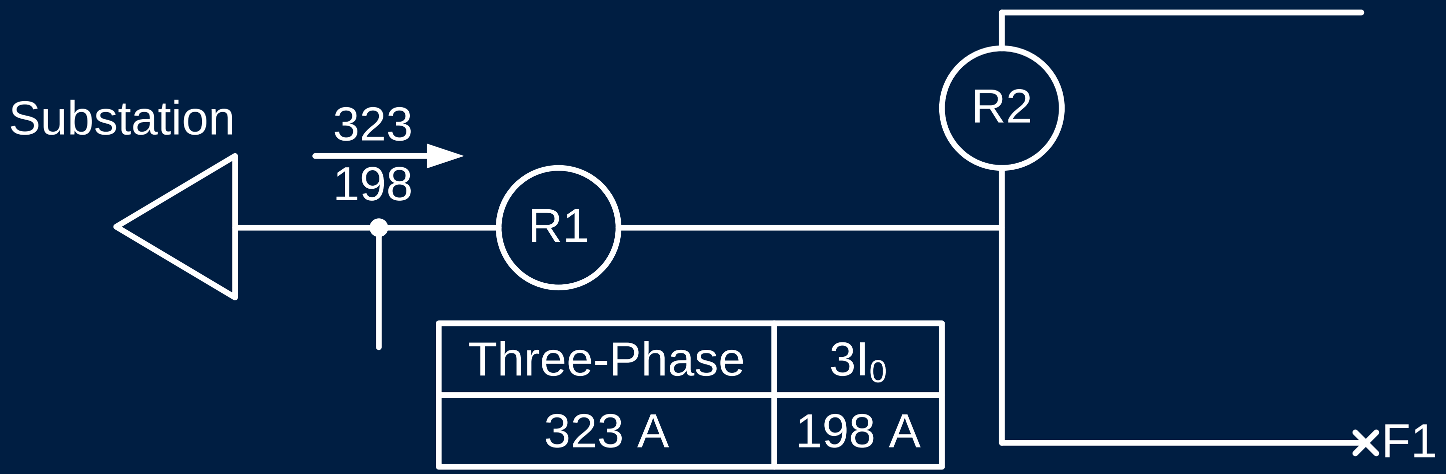
- Is caused by addition of generating sources and rotating machinery of considerable size
- Affects capability of equipment to carry and interrupt fault currents
- Requires both local and area EPS equipment ratings to be reevaluated

# Relay Desensitization

- Available short-circuit current increases with addition of DR
- Short-circuit current splits between substation and DR
- Substation short-circuit contribution can be significantly reduced when compared with value before addition of DR

# Relay Desensitization

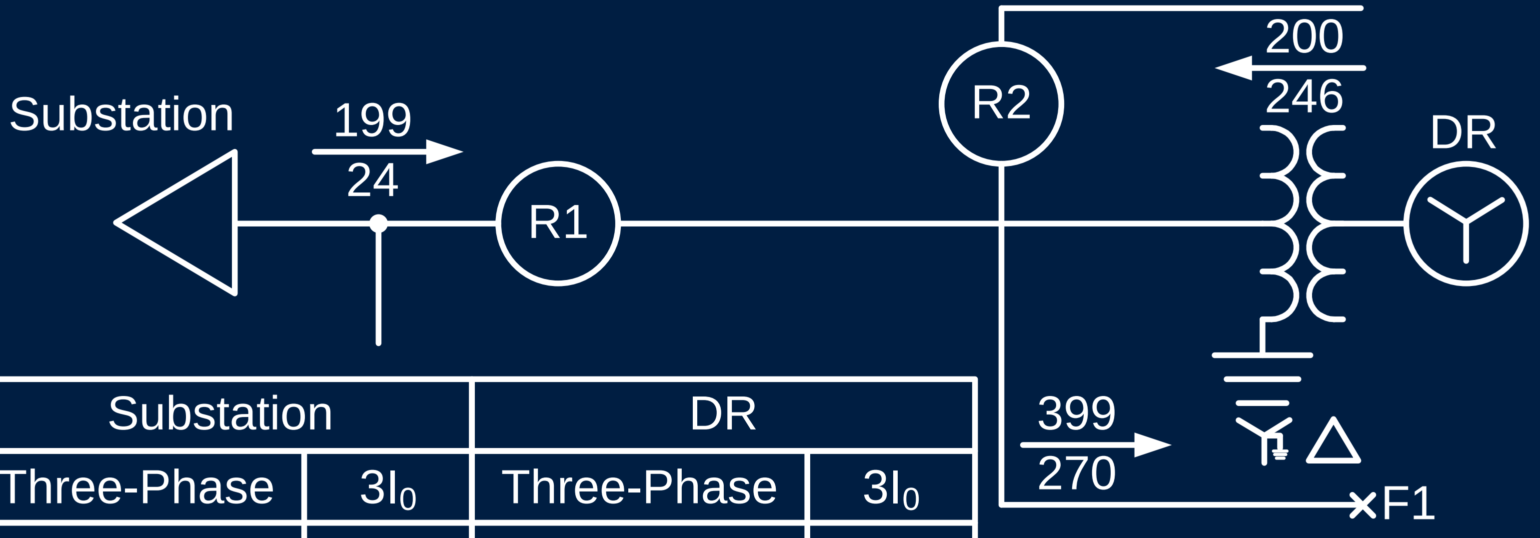
## Fault Current Distribution Without DR




| Three-Phase | $3I_0$ |
|---|---|
| 323 A | 198 A |

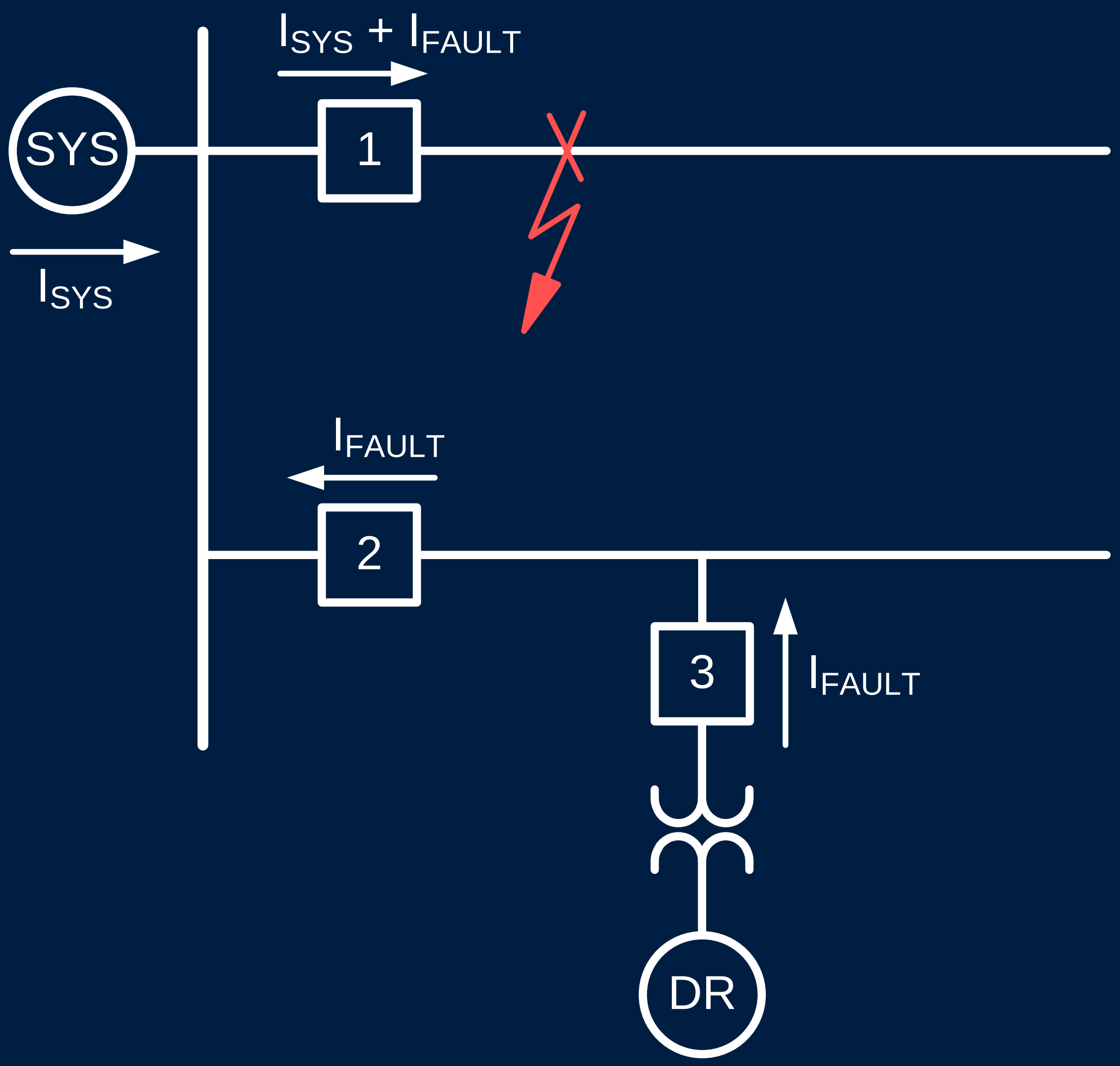
# Relay Desensitization

## Fault Current Distribution With DR




| Substation | | DR | |
|---|---|---|---|
| Three-Phase | $3I_0$ | Three-Phase | $3I_0$ |
| 199 A | 24 A | 200 A | 246 A |

# Operation for Fault in Adjacent Zone



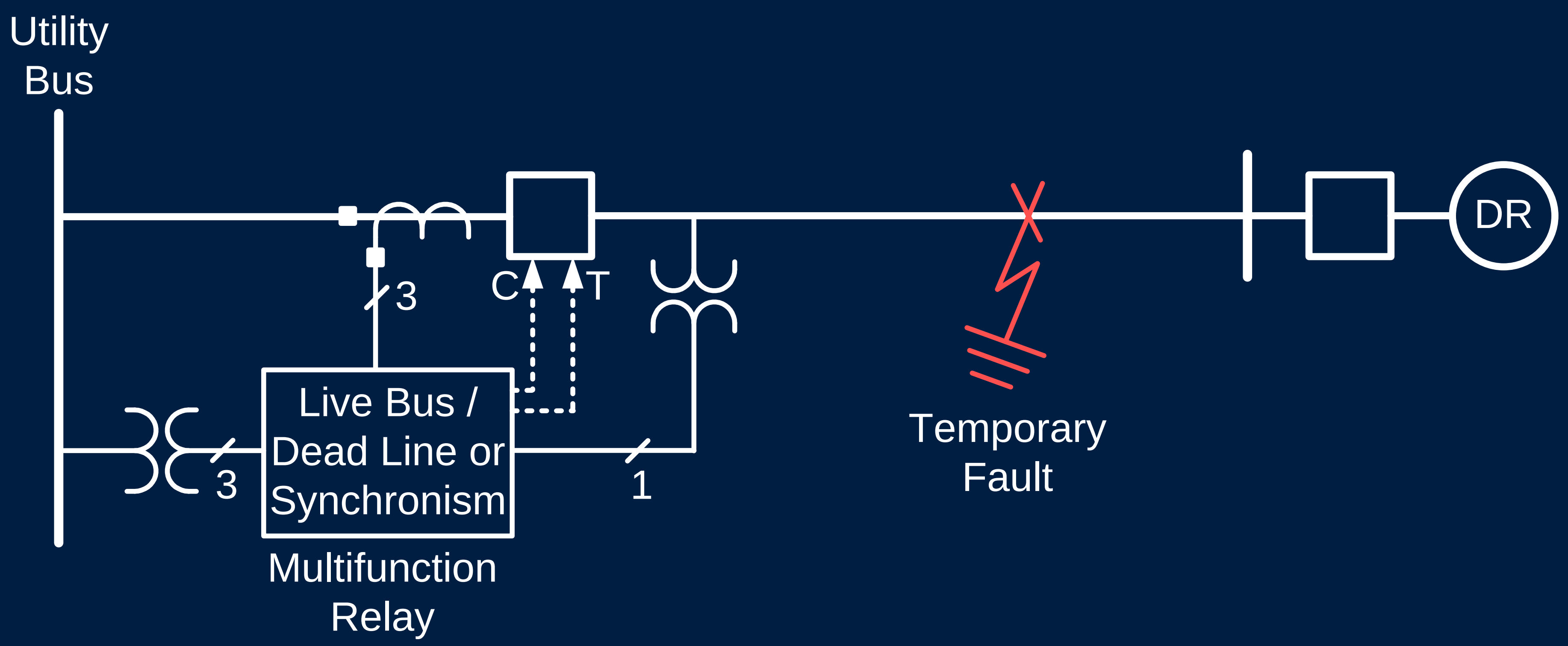
# Automatic Reclosing

- DR should be disconnected before open interval expires
  - By interconnection protection (81U, 81O, 59, 27)
  - By DTT
- Minimum open or dead time to allow arc deionization and to avoid restrike is

$$t = \frac{kV}{34.5} + 10.5 \text{ cycles}$$

# Automatic Reclosing
## Close Permissives

- Feeder and bus are in synchronism
- Utility bus is hot and line is dead

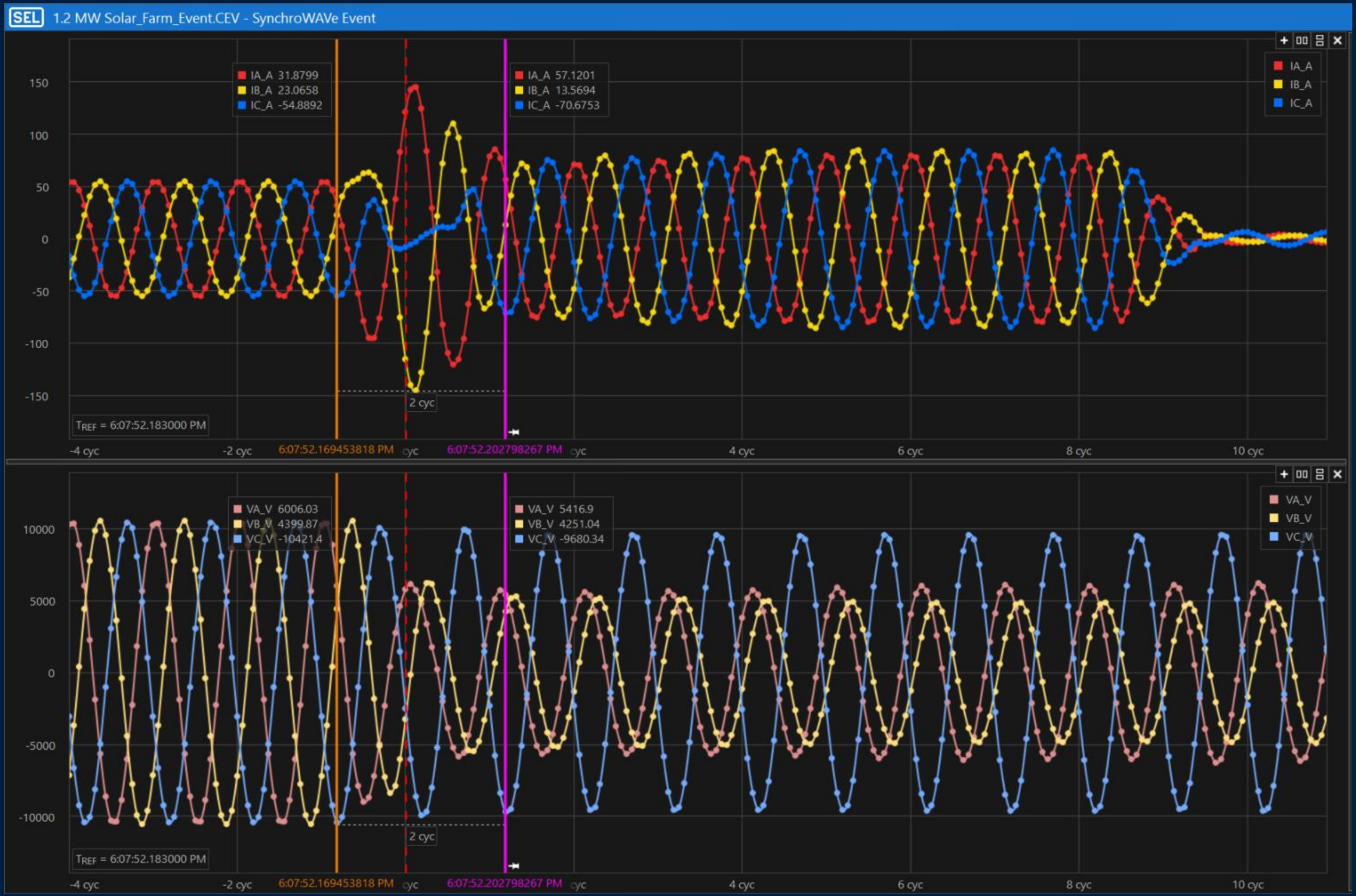


# Nonconventional Power Sources Under Fault Conditions

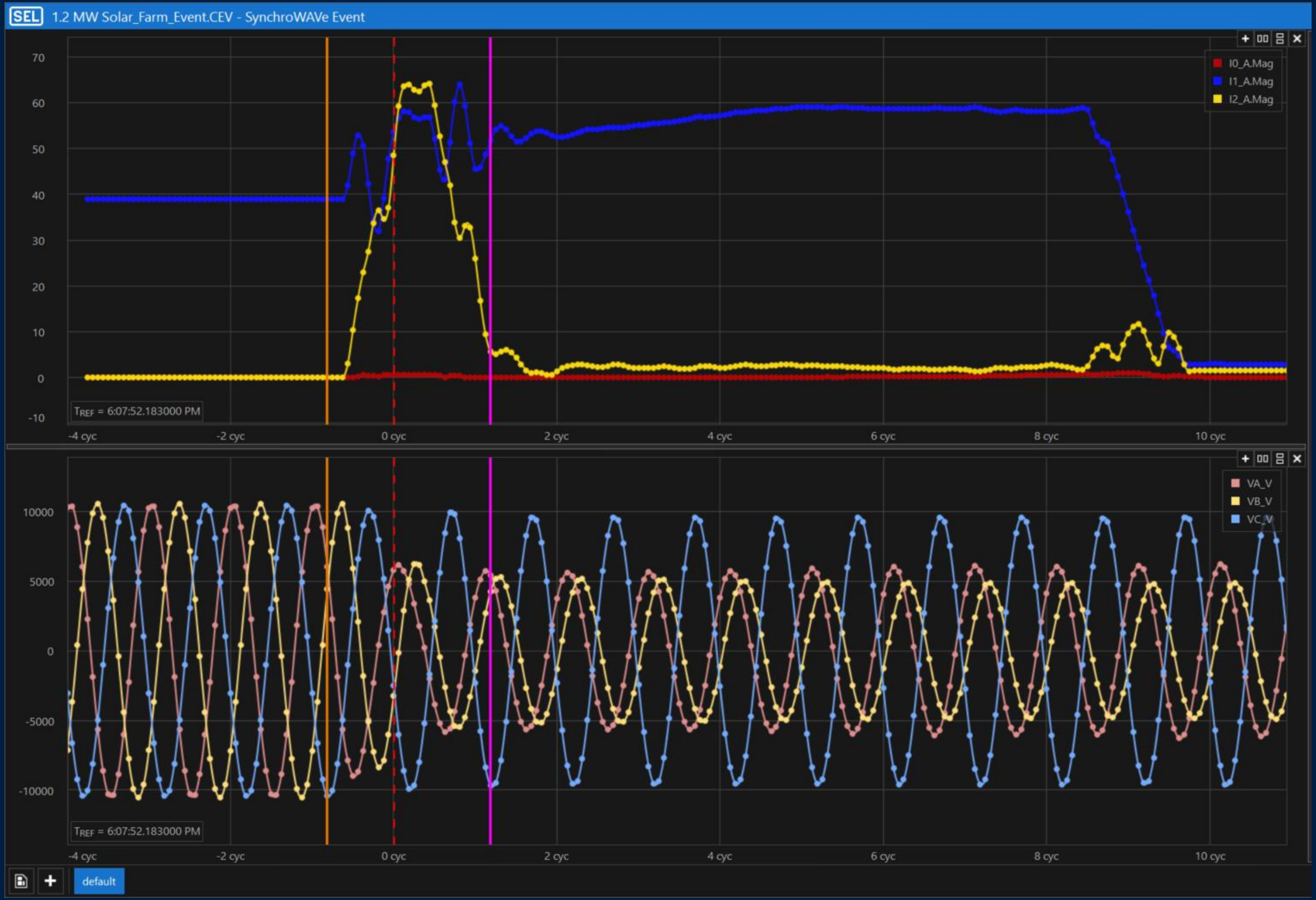
# Challenges of Nonconventional Power Sources

- Cannot be represented as voltage source behind an impedance
- Do not generate
  - Continuous fault current
  - Any fault current
- Do not generate zero- and negative-sequence currents during nonsymmetrical faults (Type 3, Type 4, and PV)

# 1.2 MW Inverter Faulted Phase Quantities

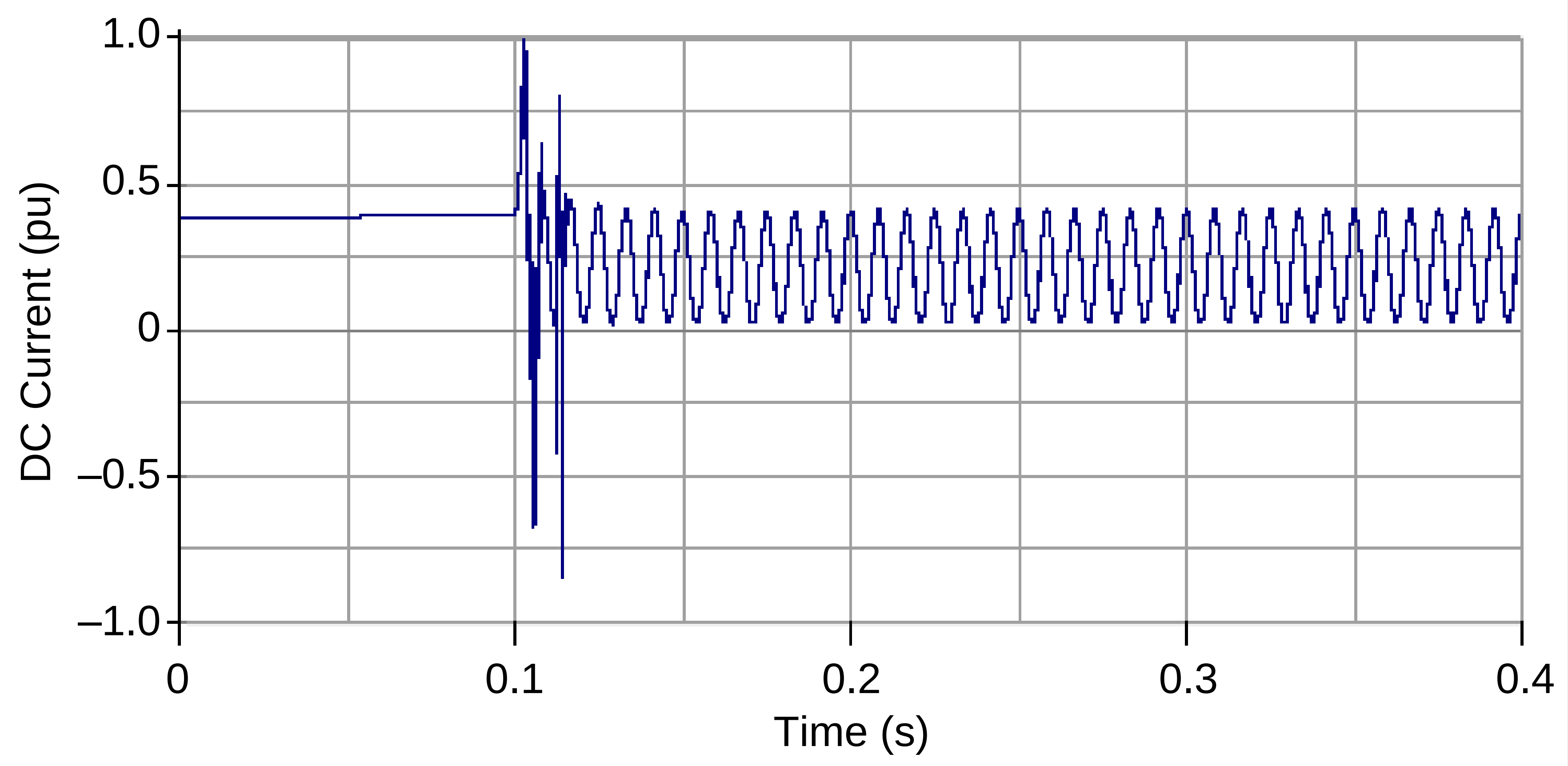


# 1.2 MW Inverter Faulted Sequence Current



# Type 4 Wind Turbine (Inverter)

## BC Fault as seen from the DC Bus ("Behind Inverter")



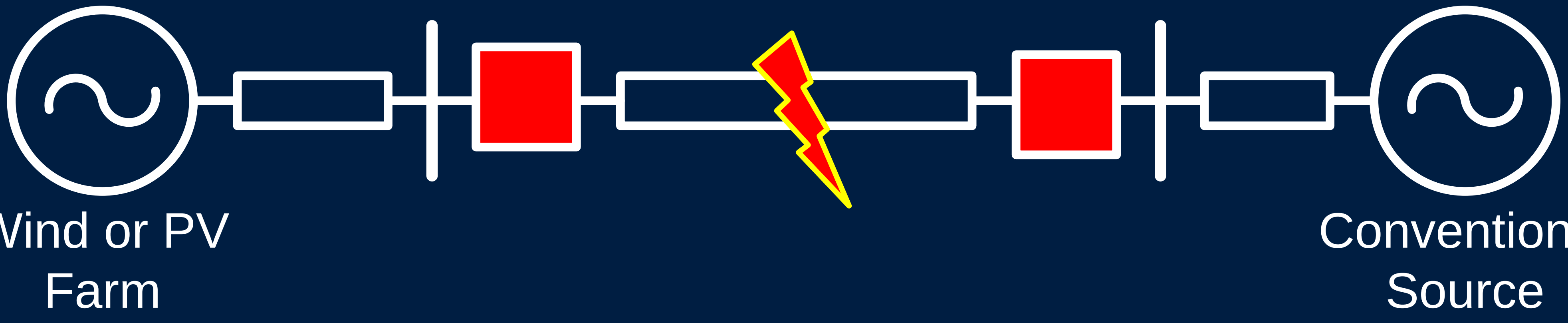
# Consequences of Nonconventional Power Source Behavior During Faults

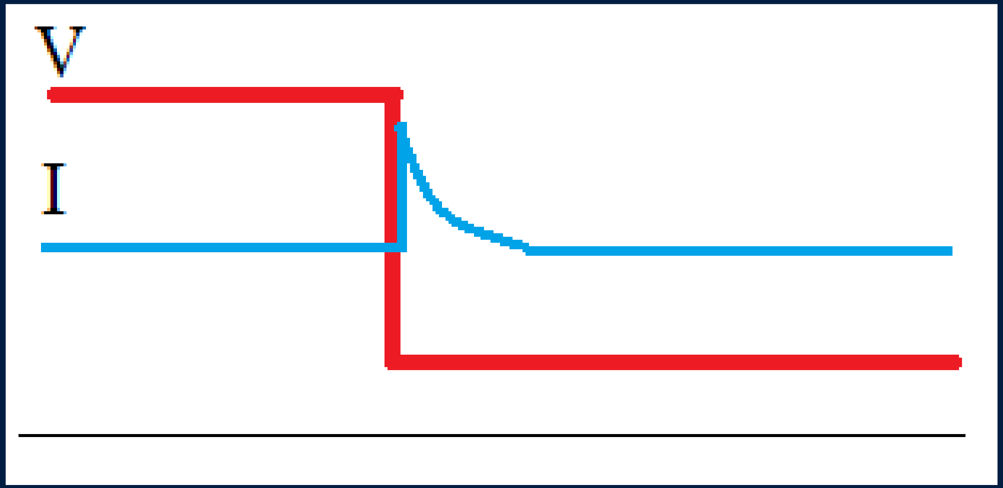
- Traditional Overcurrent Elements may not operate
  - Fault currents typically reach 1.5 to 1.7 times the inverter's maximum load current at the moment the fault occurs (fault inception).
  - 1-4 ms after fault inception, the inverter will continue to provide fault current at approximately 120% of nominal load current

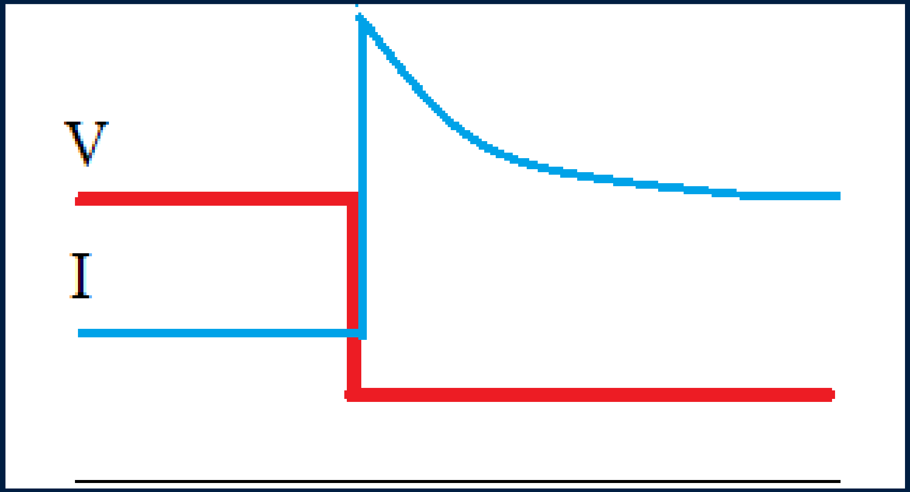
# Consequences of Nonconventional Power Source Behavior During Faults

- Directional Elements no longer work as expected
  - The inverter produces no sequence currents.
  - The microprocessor relay does not have a polarizing quantity to accurately declare a fault direction.

# Fault Behavior Summary by Source



# Anti-Islanding Protection

## IEEE 1547 general requirements to be met at point of common coupling (PCC)

# DR Response to Voltage Excursions

## Changed in 1547a-2014

| Voltage Range (% of base voltage) | Clearing Time (s) | Clearing Time: Adjustable Up To and Including (s) |
|---|---|---|
| V < 45 | 0.16 | 0.16 |
| 45 ≤ V < 60 | 1.00 | 11 |
| 60 ≤ V < 88 | 2.00 | 21 |
| 110 < V < 120 | 1.00 | 13 |
| V ≥ 120 | 0.16 | 0.16 |

# DR Response to Frequency Excursions

## Changed in 1547a-2014

| | Default Settings | | Range of Adjustability | |
|---|---|---|---|---|
| Function | Frequency Range (Hz) | Clearing Time (s) | Frequency Range (Hz) | Clearing Time: Adjustable Up To and Including (s) |
| UF1 | < 57 | 0.16 | 56-60 | 10 |
| UF2 | < 59.5 | 2 | 56-60 | 300 |
| OF1 | > 60.5 | 2 | 60-64 | 300 |
| OF2 | > 62 | 0.16 | 60-64 | 10 |

# Islanding Detection
## Elements and Typical DR Source Clearing

| SEL-751 Element | ANSI# | DR Source Clearing Time<br>Assumes 3 cycle breaker |
|---|---|---|
| Under Voltage | 27 | 0.16 – 2.0 seconds * |
| Under Frequency | 81U | 0.16 seconds * |
| Under Frequency<br>Rate of change | 81R | ≈ 7 - 34 cycles<br>Setting dependent |
| Under Frequency<br>Fast rate of change | 81RF | ≈ 7 - 10 cycles<br>Frequency rate of change dependent |
| 3 Phase Voltage Vector Shift | 78VS | ≈ 4 cycles |

* Reference IEEE 1547 – 2003™

# Possible Solutions:

## Fast Rate of Change 81RF Element
## Vector Shift 78VS Element
## Negative Sequence Overvoltage (59Q)

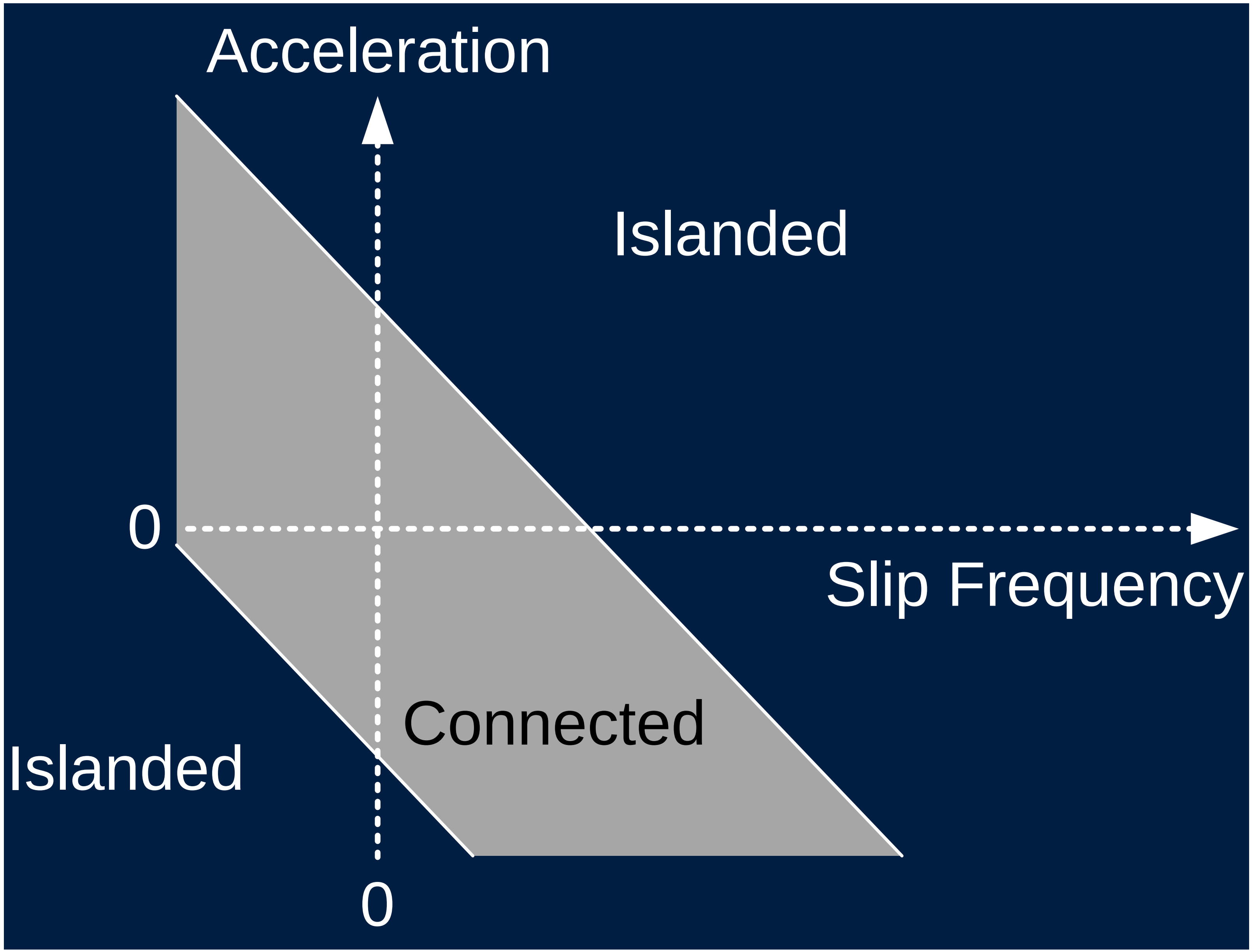
# Fast Rate of Change of Frequency

Definitions

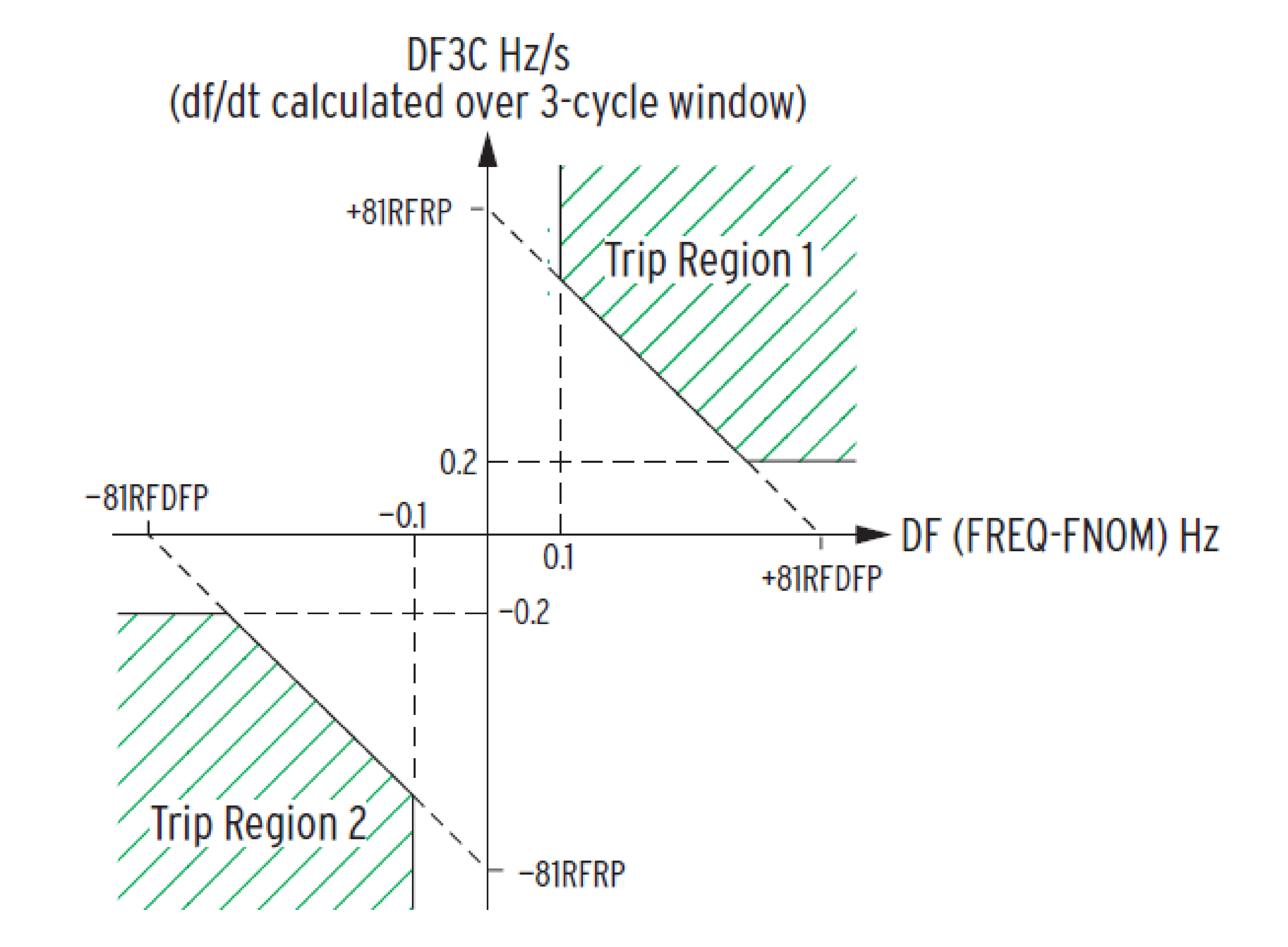
- Change in Frequency (FREQ-FNOM)
  - Slip of the frequency
- Speed of the Change of Frequency (FREQ-FNOM)/s
  - Acceleration

In words, “Not only does the frequency have to change by a certain value but it also has to change at a certain rate.”

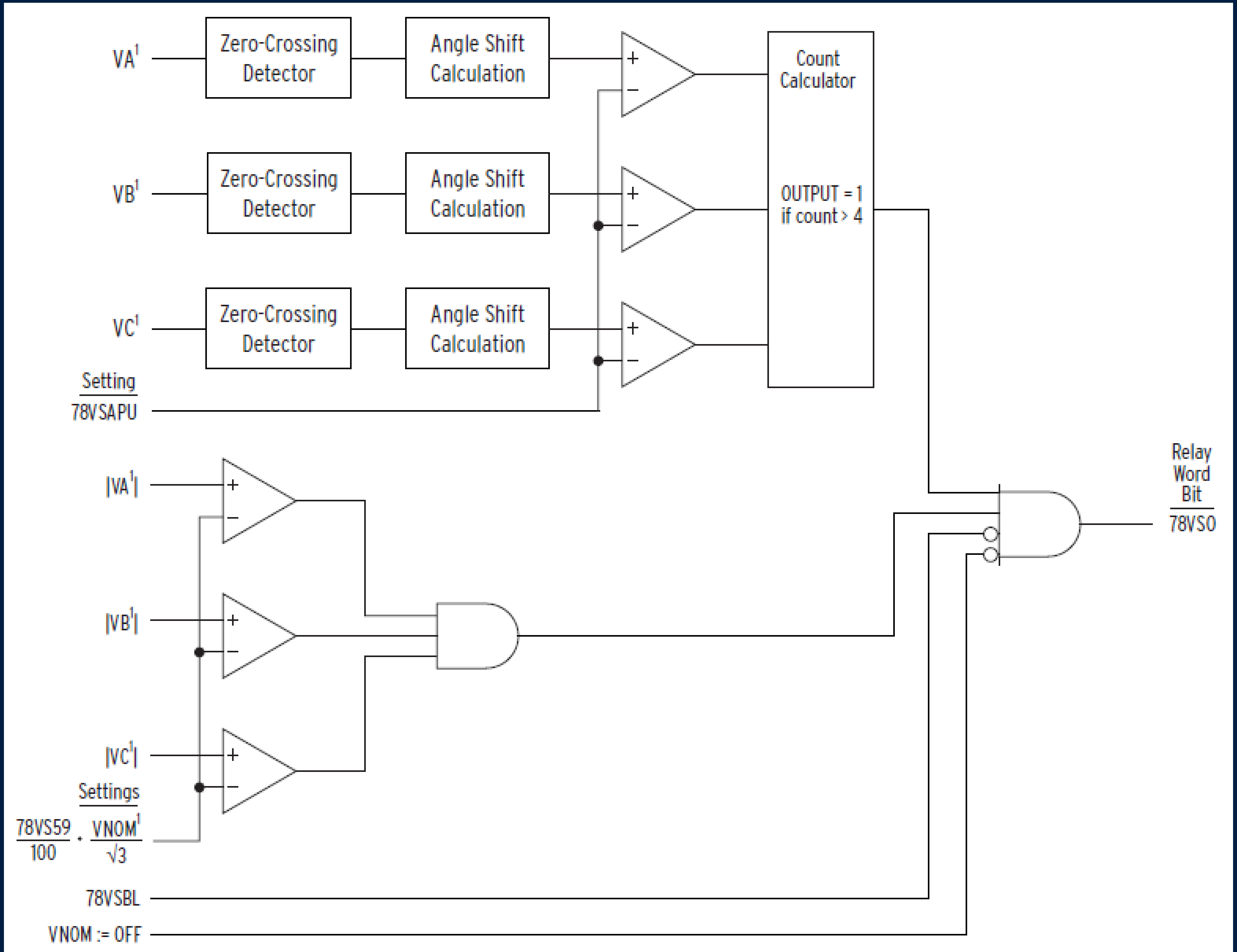
# Fast Rate of Change of Frequency



# Fast Rate of Change of Frequency Cont.



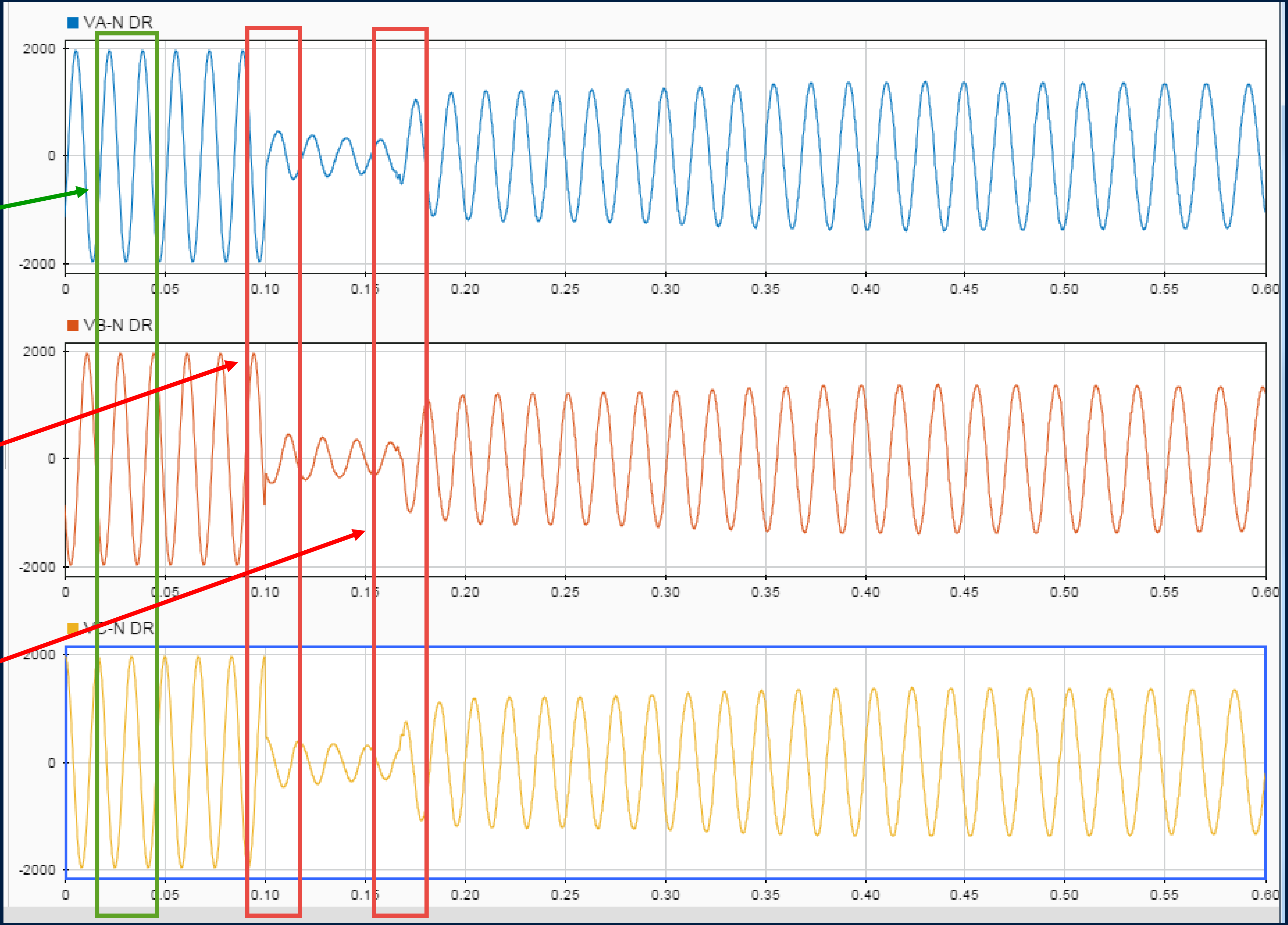
# SEL-751 78VS Element Logic From IM



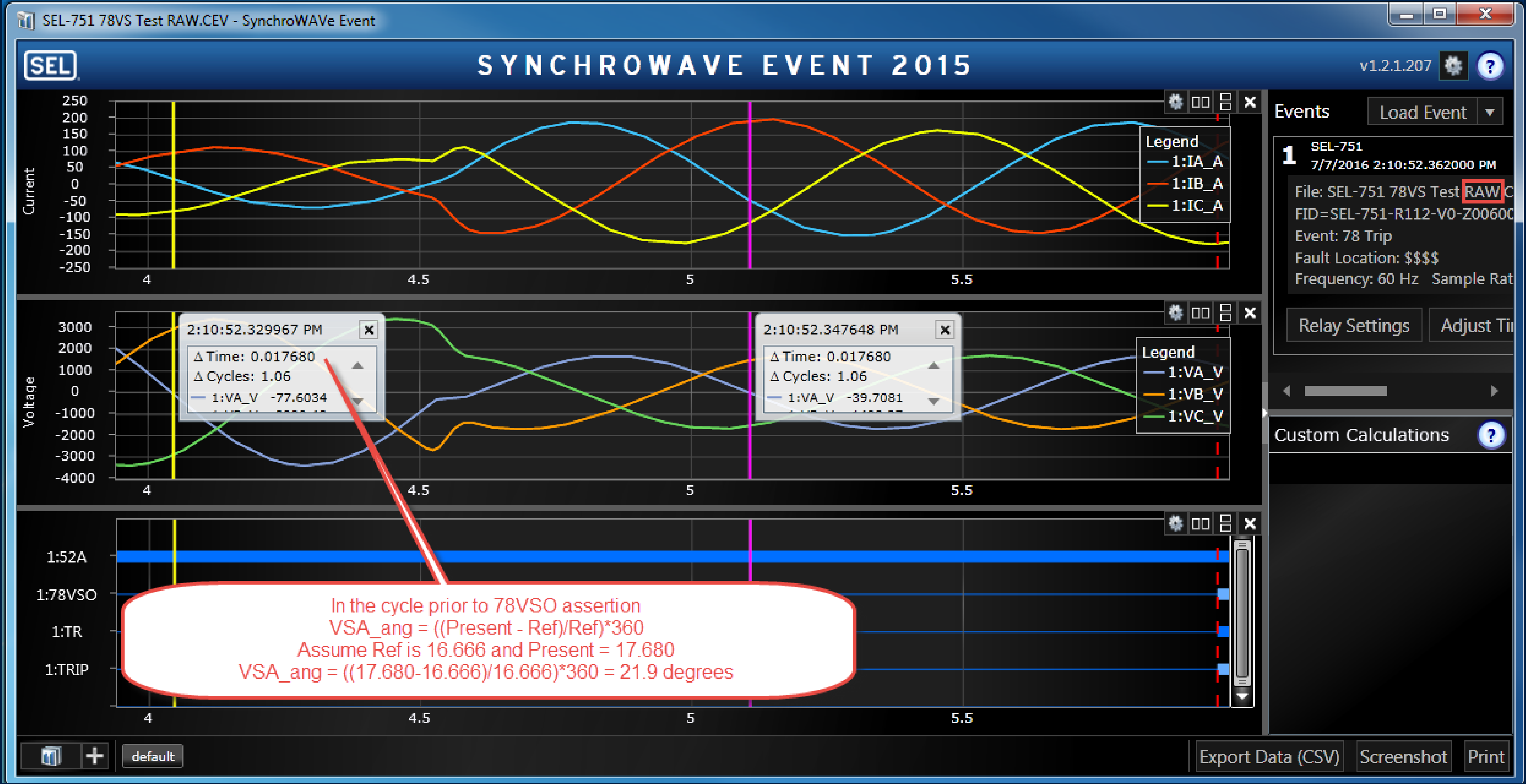
# Simulation Results

Reference Vector data

Three phase vector shift seen at inception of fault and at EPS source clearing



# Vector Shift 78VS Event Report



## Advantages of the 78VS element

- Fastest Method of islanding detection
- Relies total on DR source voltage monitoring
- Includes under voltage supervision

## Disadvantages of the 78VS element

- Requires 20% loading increase at islanding
- Requires system studies for secure settings
- Requires DR close circuit monitoring

# Islanding Detection
## Elements and Typical DR Source Clearing

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| Under Frequency<br>Fast rate of change | 81RF | ≈ 7 - 10 cycles<br>Frequency rate of change dependent |
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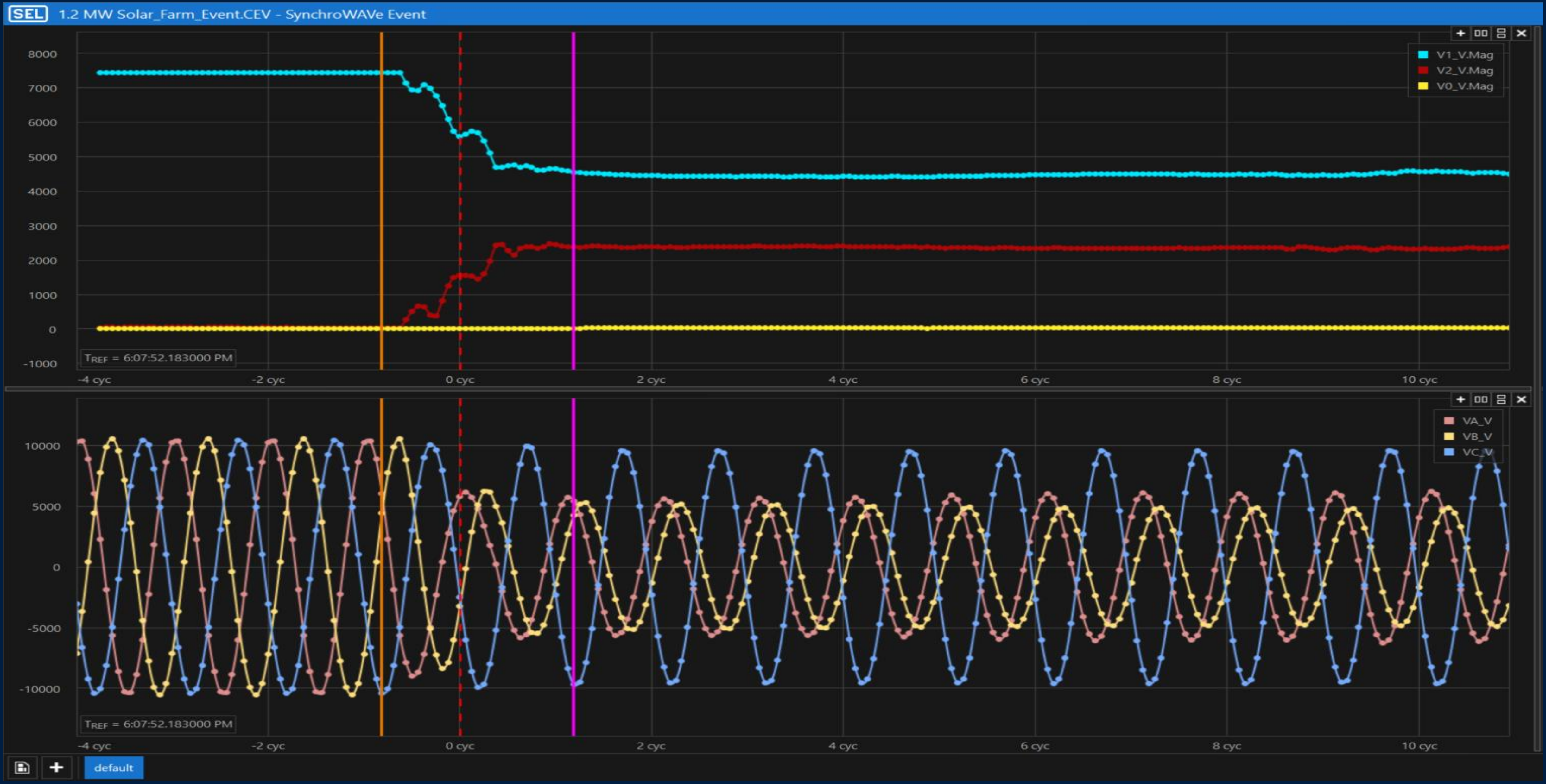
* Reference IEEE 1547 – 2003™

# Faulted Phase and Sequence Voltages of the Inverter

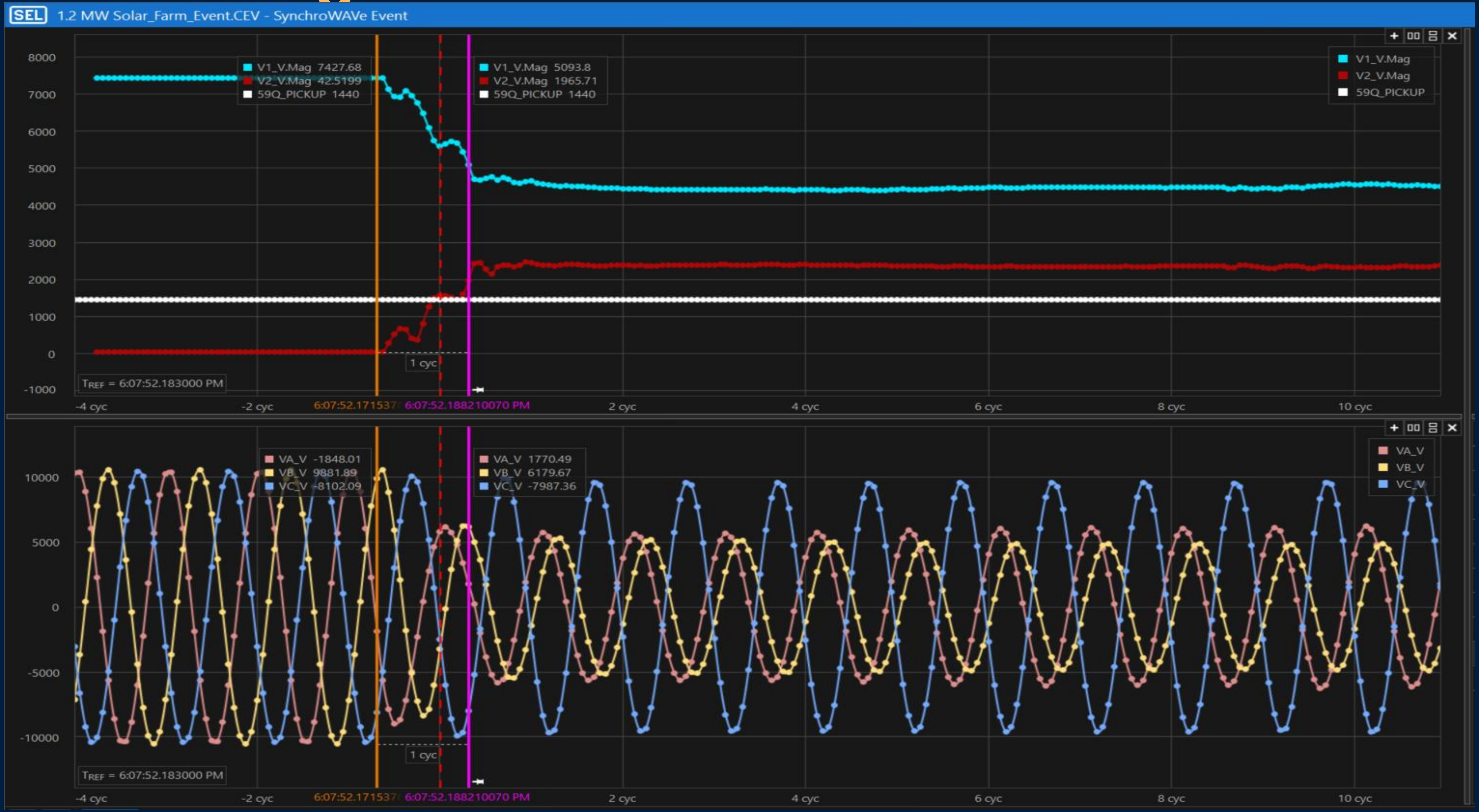


# Set a Unbalanced Voltage Element
## (Just like Weak Infeed Detection!)

- Assume maximum load conditions create a system unbalance 10%
- Assume a 5% safety margin
- The nominal system line-to-neutral system voltage in the previous example is 7.2 kV

59Q Pickup = 7.2 kV * (10% + 5%)
59Q Pickup = 1.08 kV

# Evaluating Weak Infeed For the Inverter Fault



# Communications Assisted Tripping

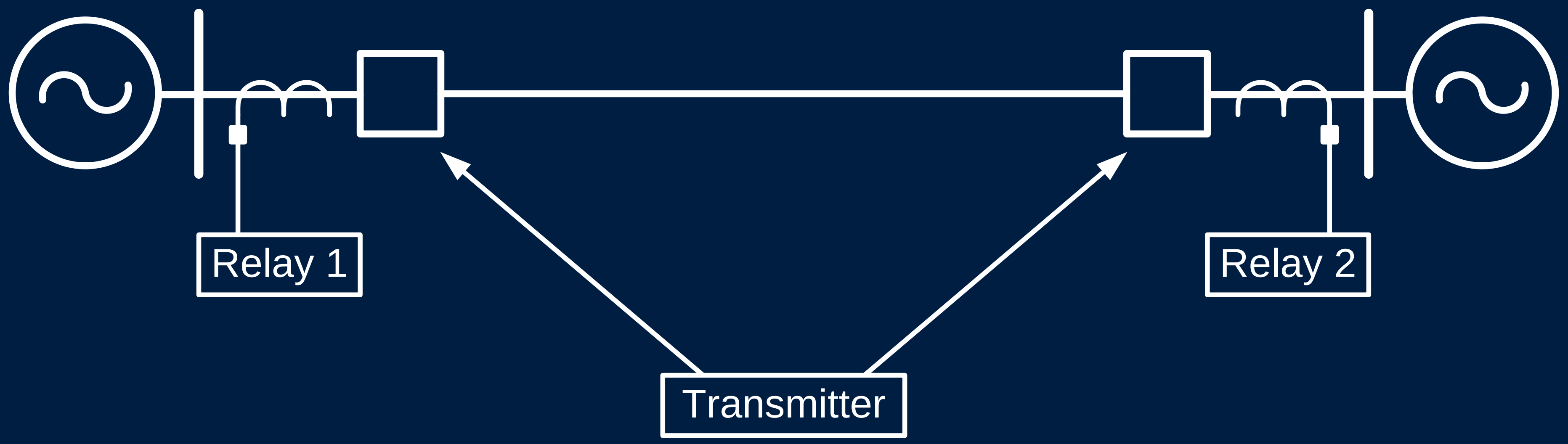
# Why Are Pilot Protection Schemes Required?

- Safeguard system stability
  - Minimize fault-clearing times
  - Allow high-speed reclosing
- Reduce equipment damage
- Improve power quality – reduce voltage sag duration
- Provide coordination – long-line and short-line applications

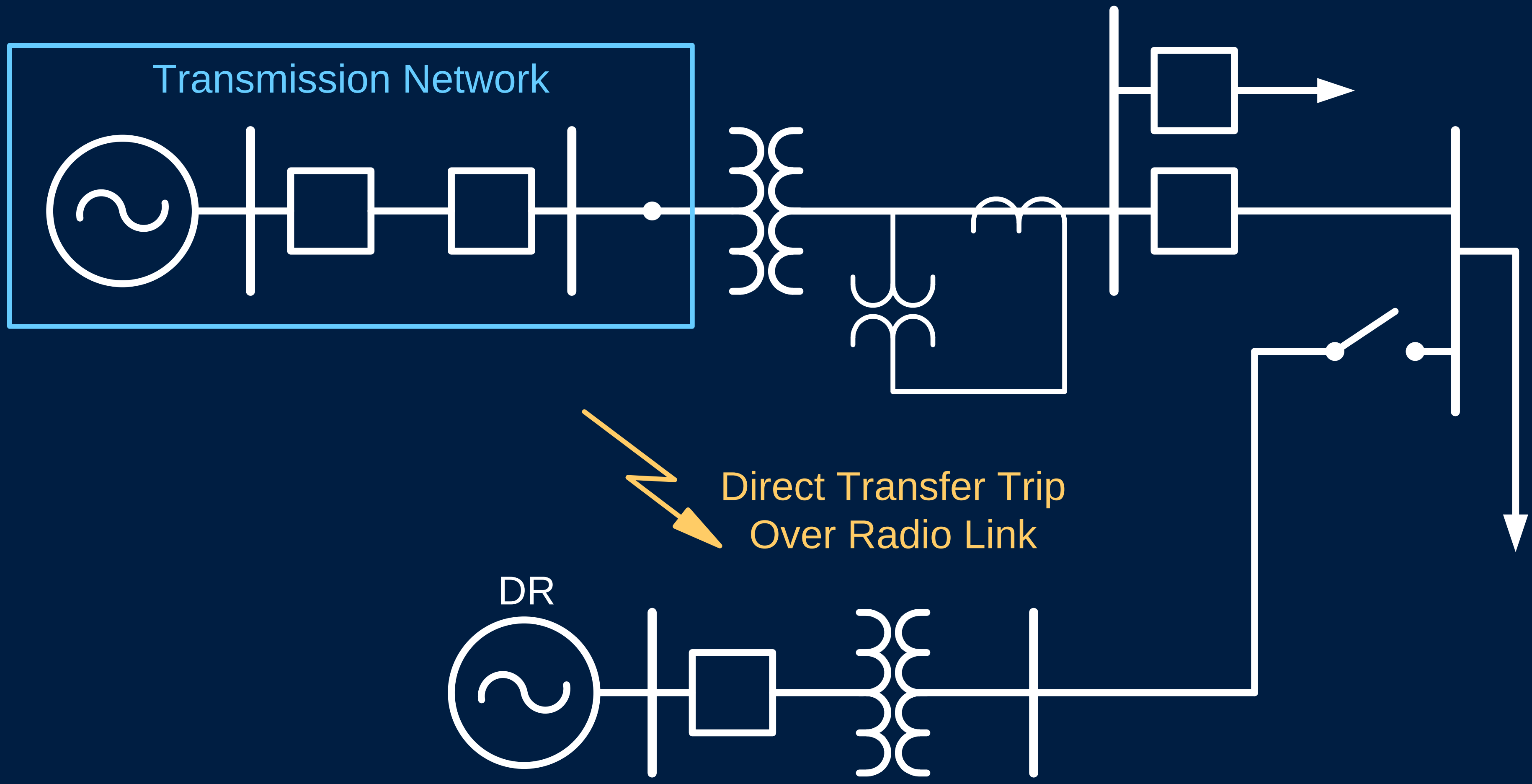
# Types of Directional Comparison Protection Schemes

- DTT
- POTT
- PUTT
- DCB
- DCUB

# DTT Scheme



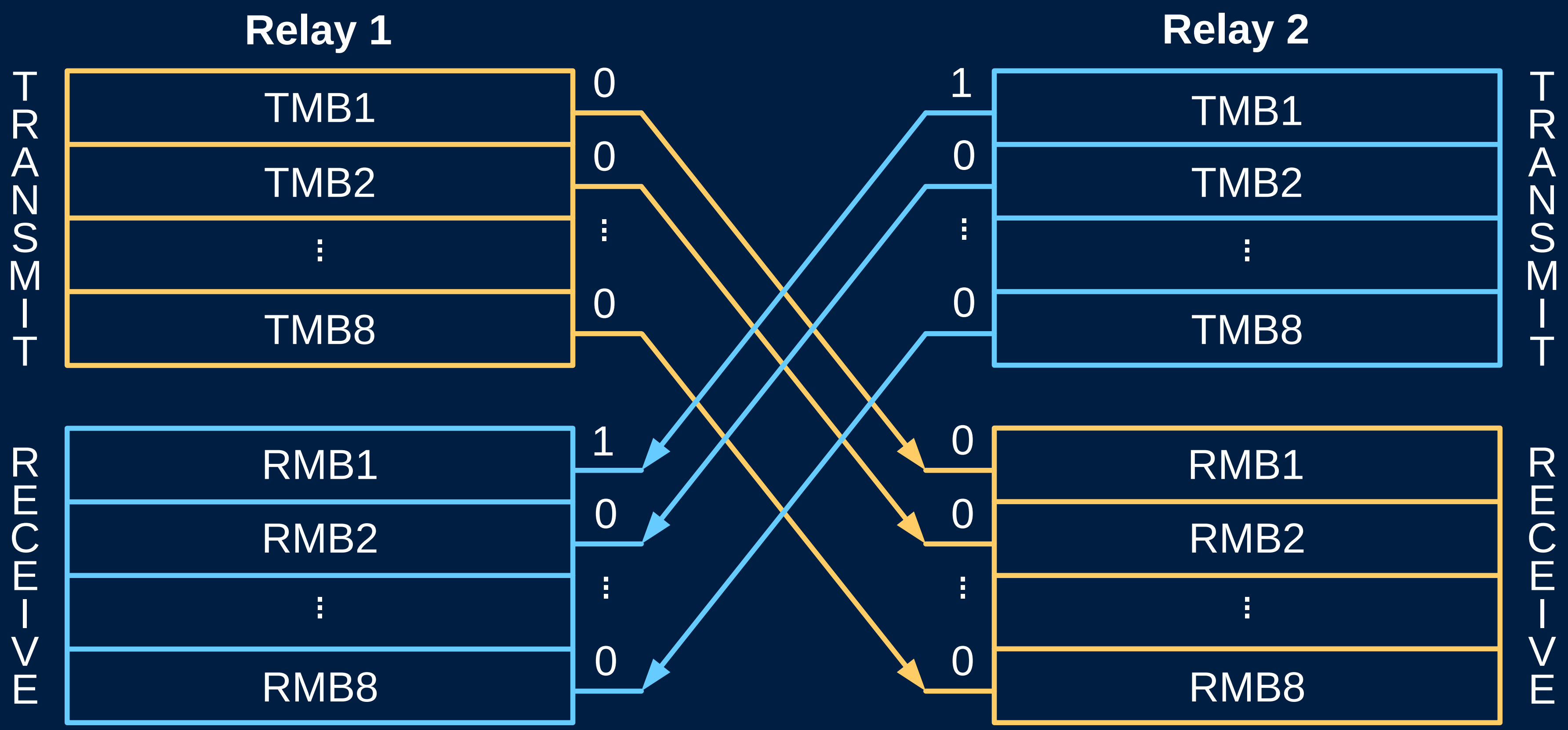
# Applying MIRRORED BITS Technology and Serial Radios for DTT



# Mirrored Bits Communications

# Mirrored Bits Communications

## Transmit “Mirrored” to Receive



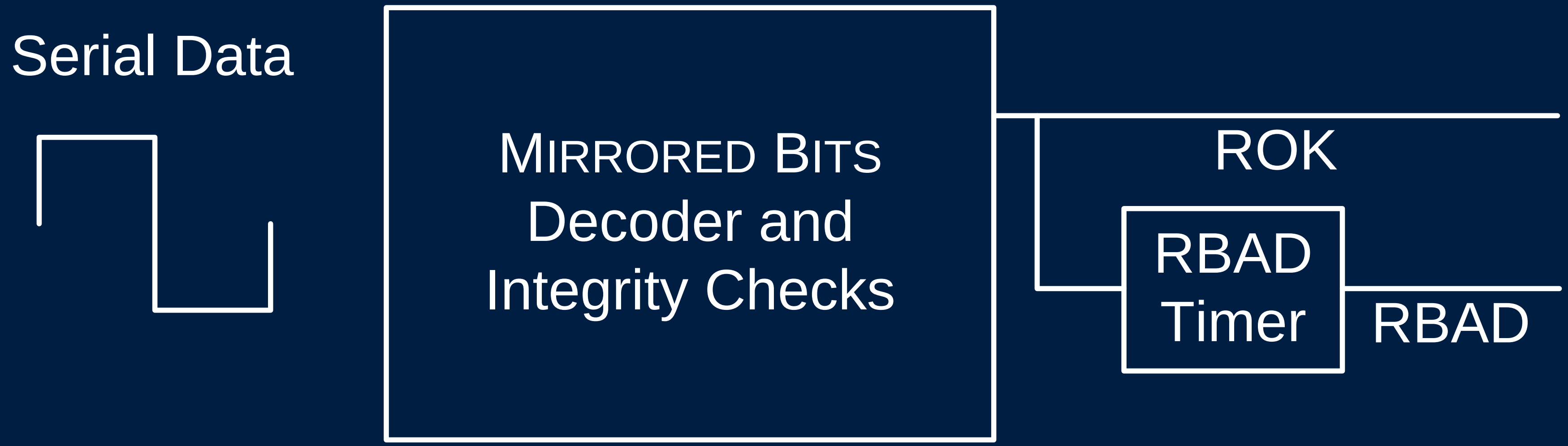
# Understanding MIRRORED BITS Message

- Each message consists of 4 bytes
- Each byte contains 1 start bit, 6 TMBs, 1 parity bit, and 1 stop bit
- Each of the 8 TMBs is repeated three times within these 4 bytes
- Selected TMBs are inverted based on TX_ID setting to provide unique address used for loopback detection

# Mirrored Bits Performance Monitoring

- When Mirrored Bits channel is operating correctly, ROK bit is set to 1
- When channel is disturbed, ROK drops out

# Understanding ROK and RBAD



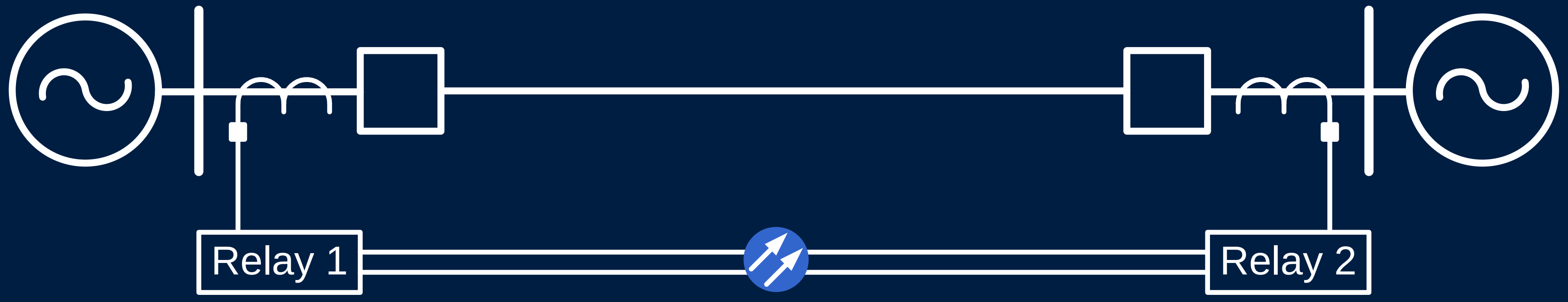
# How Does CBAD Bit Work? How Would I Use It?

- Problem – channel is experiencing many short noise bursts (intermittent)
- Solution – CBAD provides means to measure and report channel unavailability

# MIRRORED BITS Communications

## Relay Without MIRRORED BITS


## Relay With MIRRORED BITS



# Relay Communications Media

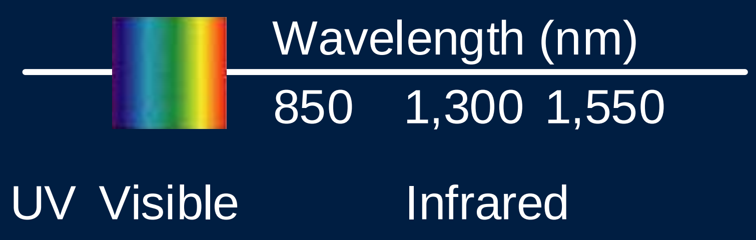
# Types of Digital Communications

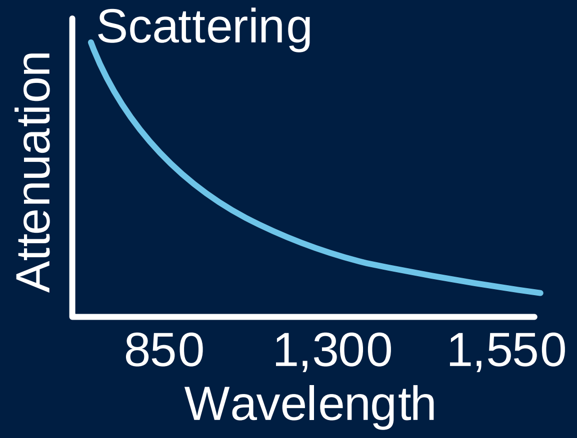
- Direct fiber
- Multiplexed fiber optics
  - SONET
  - Ethernet
- Digital radio

# Benefits of Fiber-Optic Cable

- High bandwidth
- Low attenuation
- Noise immunity
- Dielectric properties
- Lightweight
- Small size
- No arcs

# Wavelength



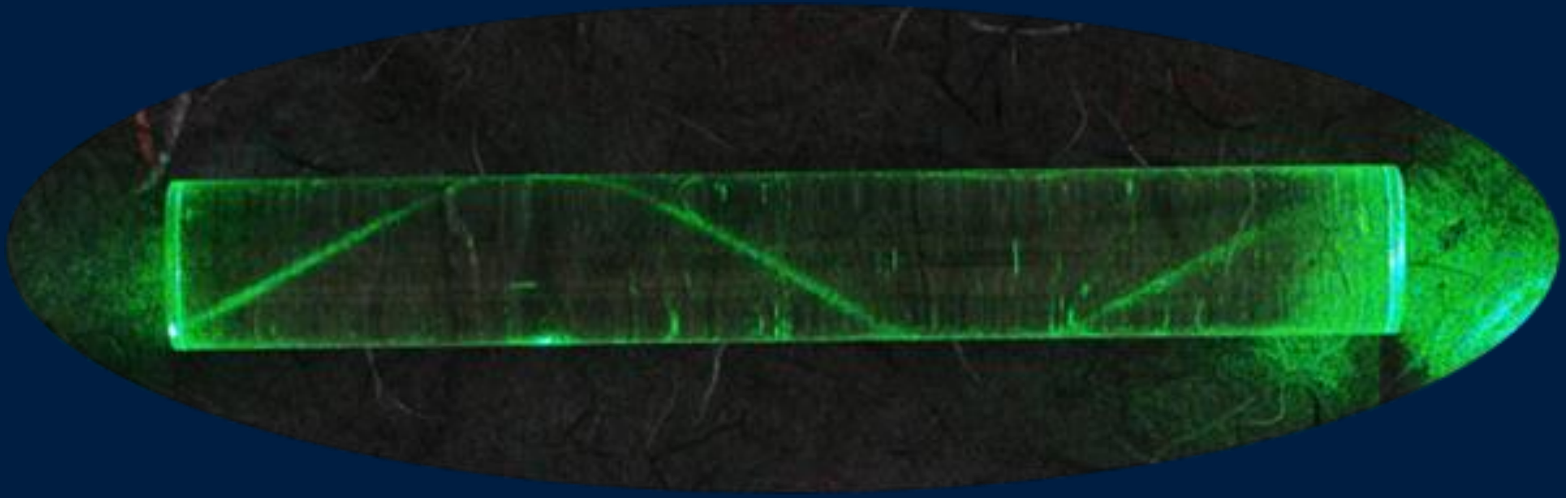




- Wavelength is “color” of light in electromagnetic spectrum
- Attenuation of glass is reduced at higher wavelengths
- Standard wavelengths are 850, 1,300, and 1,550 nm

Now select the “pipe” to transmit the signal through

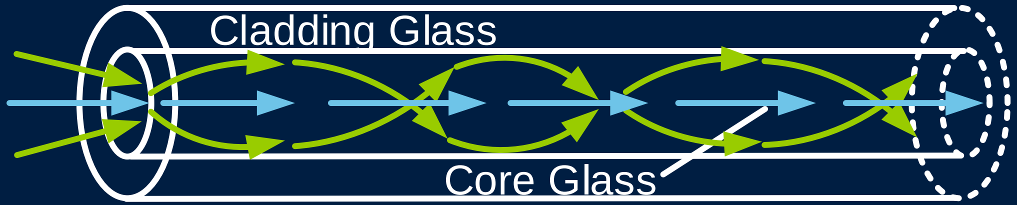
# Fiber-Optic Cable Design

- Cladding bends light waves back toward fiber center and prevents leaking
- Core is glass medium through which light travels



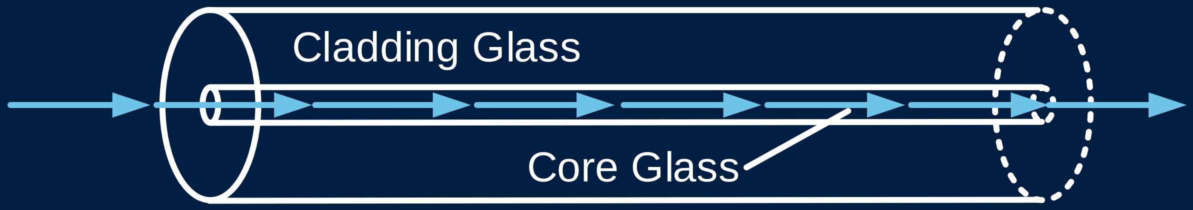
# Multimode Fiber

- Operates best at 850 and 1,300 nm
- Has core diameter of 50, 62.5, or 100 µm (large)
- Uses LED to transmit
- Disperses light waves into numerous paths as they travel through core
- Is good for short and medium distances (within building or campus)
- Has blue or orange jacket

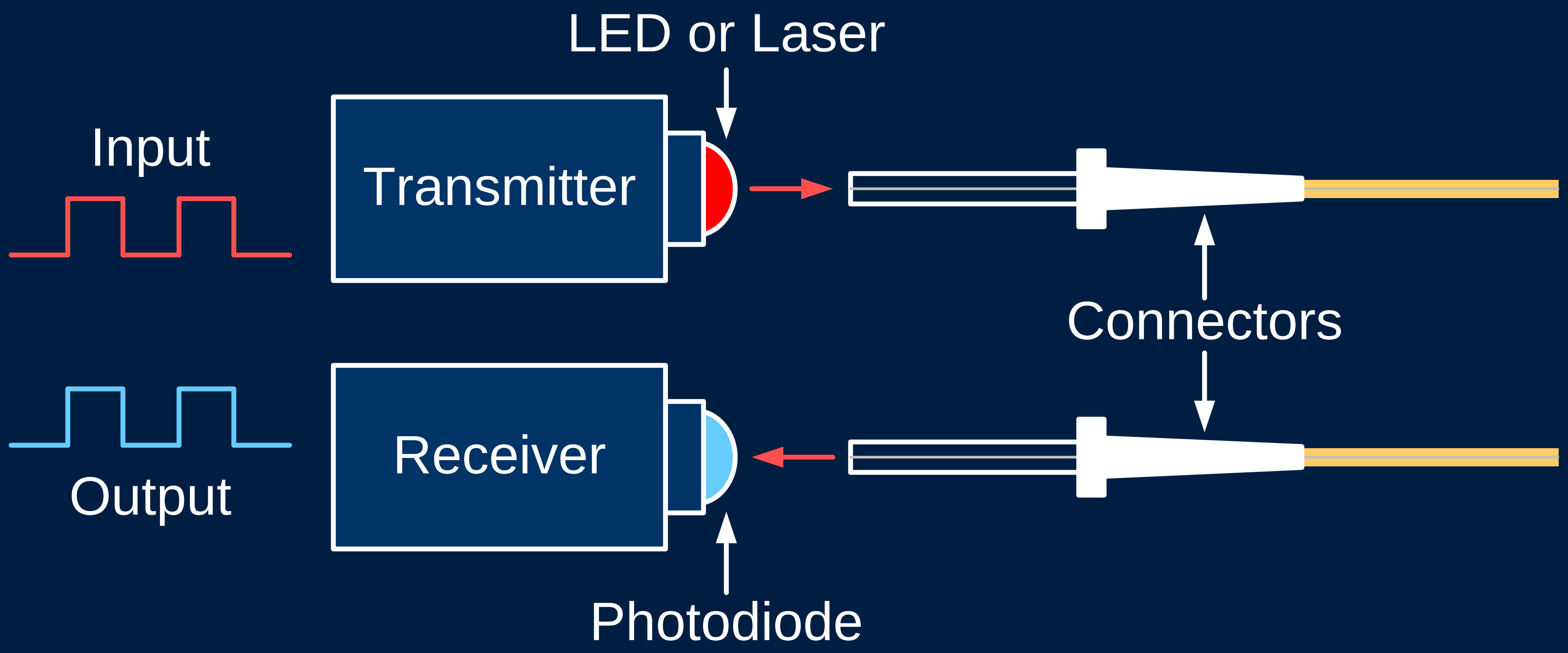



# Single-Mode Fiber

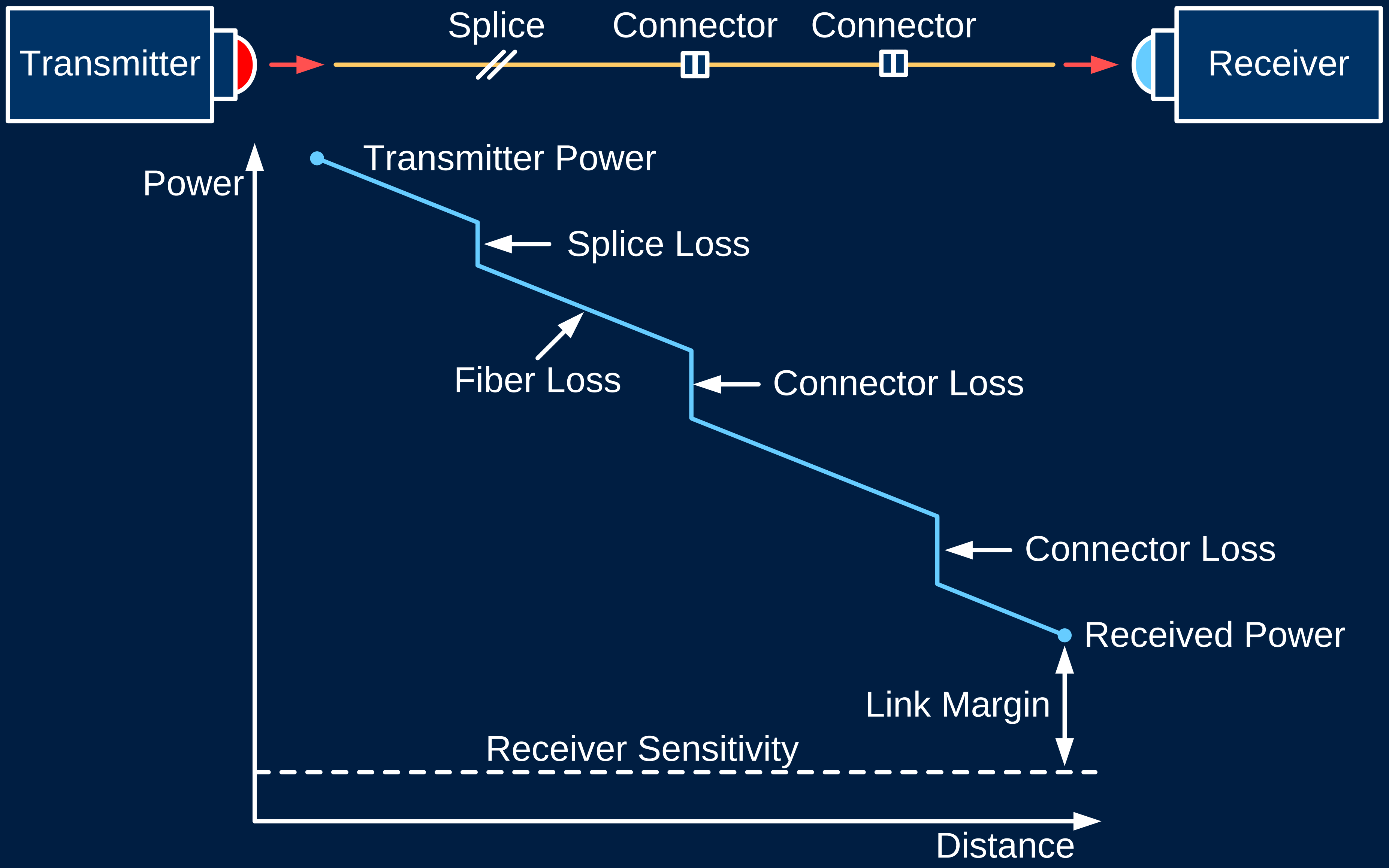
- Operates best at 1,300 and 1,550 nm
- Has core diameter of 8 to 10 µm (narrow)
- Uses laser diode to transmit
- Includes no distortion from overlapping light pulses
- Has higher bandwidth than multimode, up to 50 times more distance
- Has yellow jacket




# Fiber-Optic Data Transmission



# Link Loss Budget



# Considerations When Choosing Wavelength and Fiber Type

- Distance to cover
- Necessary bandwidth
- Budget
  - Fiber itself
  - Transmission hardware
- Multiplexer involvement (IEEE C37.94)

# Conclusions

- An Inverter cannot be represented as voltage source behind an impedance like traditional power sources
- Traditional Distribution Protection struggles to detect fault currents supplied by inverters because inverters do not generate high fault or sequence currents
- Voltage elements area possible alternative to over current elements (Vector shift is the fastest anti-islanding detection method).
- Communications-Assisted Tripping schemes are a simple and effect way to provide protection for a DG

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