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# Cable Powering

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# Powering Method

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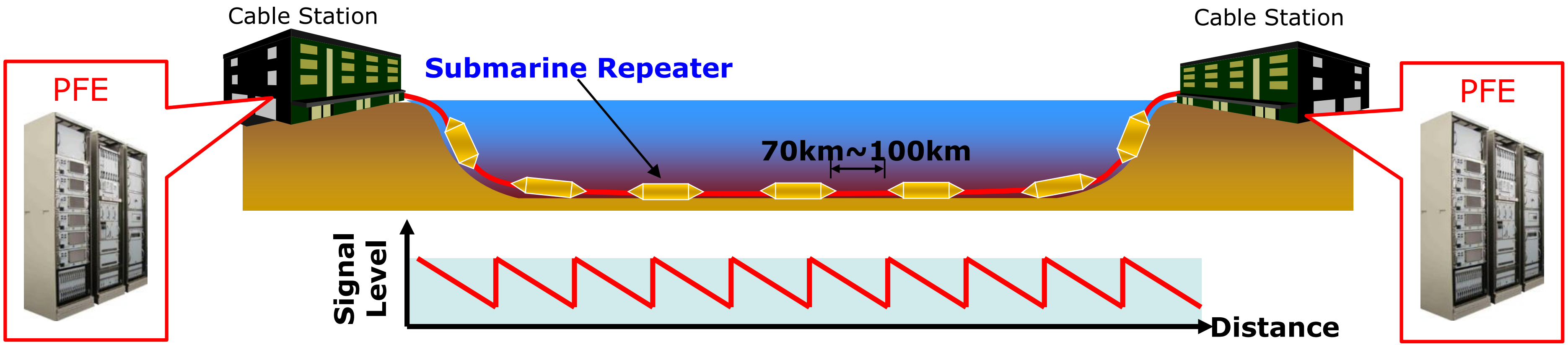
# Purpose of Powering Feeding

## To supply stable power to submersible repeaters

<u>General Requirement :</u>

- Stable power supply and high voltage applied up to 15kV for trans oceanic application
- High reliable power feeding system for operate 25 years or more
- Safety operation to personnel and system
- Fault analysis in case of cable failure



# Powering Method

## AC or DC ?

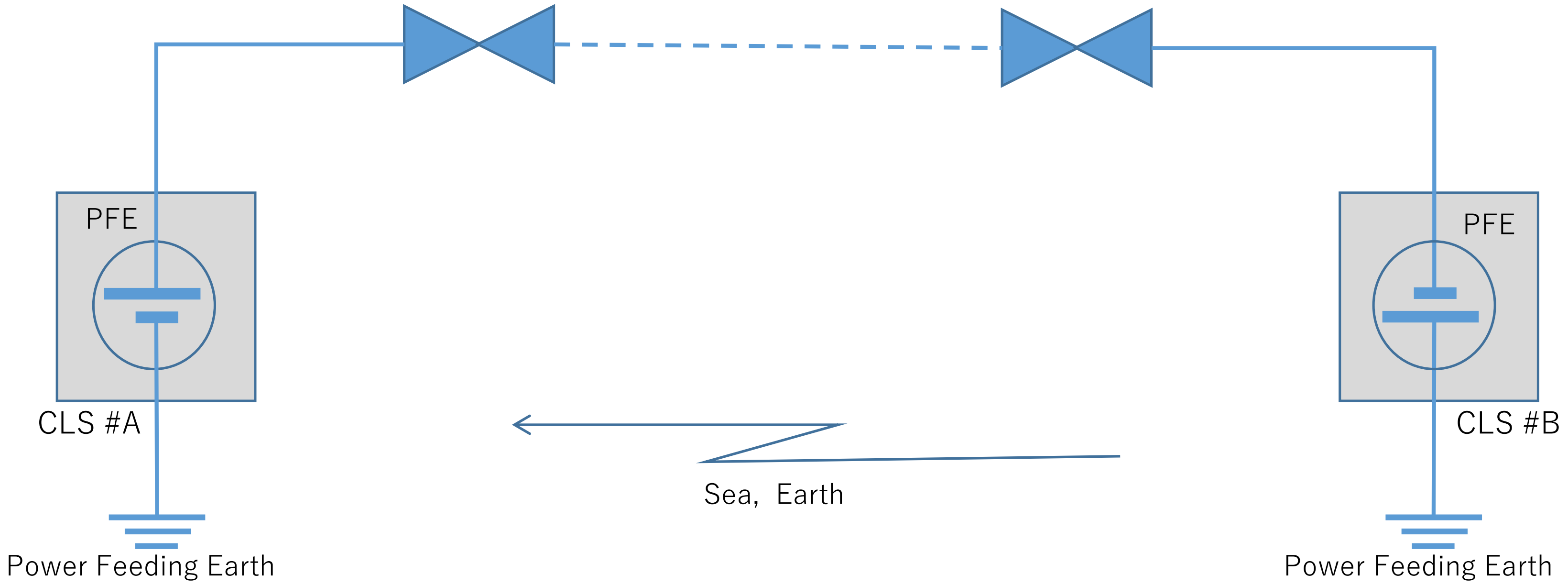
- AC
  - Easy for voltage conversion
    ➔ Flexible for voltage apply to repeater
  - Need transformer and rectifier in each repeaters
    ➔ complicated power circuit in each repeater, less reliability…

## Parallel or Series?

- Parallel
  - Supply current becomes sum of each repeater’s current
    - ➔leading huge current and voltage drop through cable …
    - ➔Receiving voltage at each repeaters becomes unstable…

# Powering Method

✓Direct Current and Series Circuit are applied for all submarine cable system




PFE : Power Feeding Equipment
CLS : Cable Landing Station

# Powering Design

# Power Feeding Design Parameters

## Specification of Power Feeding Equipment (PFE)

- Specified to generate maximum voltage under constant current

Consideration;

- Power feeding configuration
- Power feeding budget
- Margin consumed by repair

## Withstand voltage limitation : up to 15KV

- Taking into consideration all the devices; submersible plant, land/beach joint, land cable

$$\textbf{Constant} = \mathbf{V}^{nt}$$

*where* $V$ : *apply voltage*
$n$ : *device-specific parameter*
$t$ : *elapsed time to failure of device*

- Maximum power feeding voltage must be less than the withstand voltage of all devices, reducing maximum voltage is more preferable to have an additional margin of safety

# Power Feeding Budget

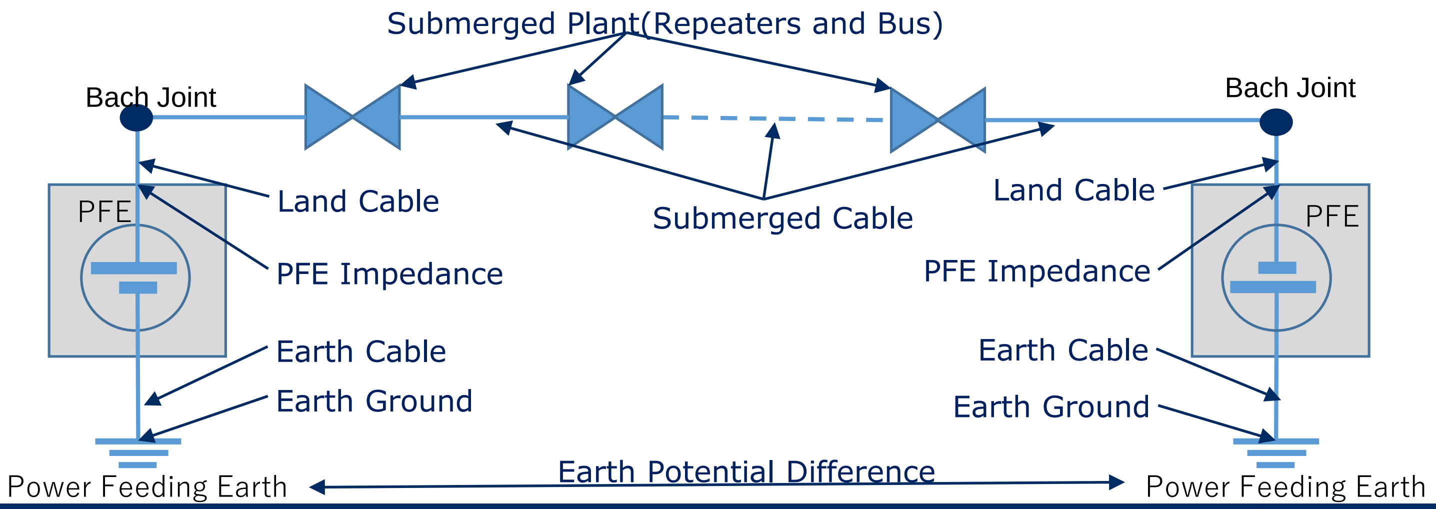
✓ Aggregate the effects of all components contributing to voltage drops along electrical path

$$V_{SYSTEM} = V_{EARTH\_GROUND} + V_{EATH\_CABLE} + V_{PFE} + V_{LAND\_CABLE} + V_{SUB\_PLANT} + V_{SUB\_CABLE} + V_{EPD} + V_{REPAIR}$$

where,

$V_{SUB\_CABLE}$ = Cable Resistance x Cable Length x Feeding Current

$V_{SUB\_PRANT} = \Sigma V_{REP} + \Sigma V_{BU}$



# Power Feeding Current

## Power feeding current is derived from repeater current requirement to maintain stable amplification characteristics

- Repeater optical output power
  - Power efficiency of Pump Laser Diode (LDs)
- Power consumption of control circuit
- Margin for electroding current

Current distribution in a repeater

| Parameters | Proportion | Remarks |
|---|---|---|
| LD current for the specified optical output power | 80% | Approx. 10% End Of Life margin |
| Current for LD control circuit | 10% | |
| Electroding margin | 10% | Nominally 80mA margin |

# Margin Design

## Earth Potential Voltage (EPV)

- Potential difference between both PFE earths due to Earth’s magnetic field
- In general, earth potential changes is caused by movement of the Earth’s mantle.
- 0.1~0.3V/km (EPV) is considered based on historical experience.

| System | | PFE voltage | | c) Earth Potential Difference | |
|---|---|---|---|---|---|
| Link | Length (km) | a) Calculation | b) Measured | Volts | V/km |
| Japan-Guam | 3,743 | 4,404 | 4,352 | -52 | -0.01 |
| Guam-Australia | 7,130 | 7,296 | 7,189 | -107 | -0.02 |
| Malaysia-China | 2,632 | 4,339 | 4,469 | 130 | 0.05 |
| Singapore-Phillippin | 2,789 | 4,073 | 4,208 | 135 | 0.05 |
| Japan-Taiwan | 2,792 | 4,617 | 4,646 | 29 | 0.01 |

## Repair Allowance

- Design life of 25 yeas, cable repair must be considered.
- Cable repair requires additional cable insertion, typically 2.5 times of water depth per repair. Additional cable insertion cause cable voltage drop.

# Power Feeding Voltage and Max. Capacity

✓ For ultra-long system, maximum voltage of PFE limits the max. capacity

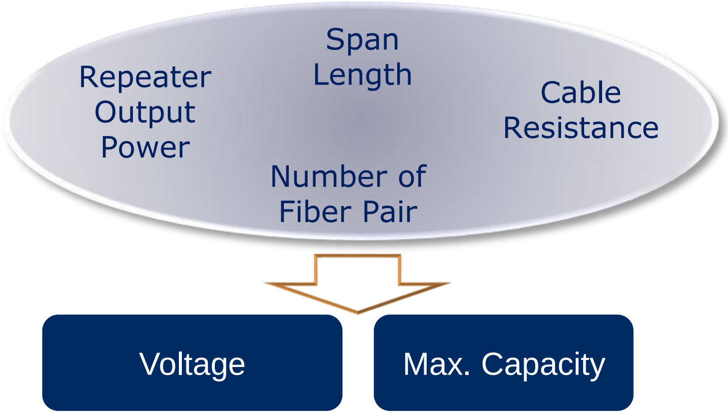
**Cable Capacity**

- Number of fiber pairs ($N_{FP}$)
- Repeater Bandwidth (BW)
- Shannon SE [G-OSNR ($N_{REP}$,ROP,Fiber,L,BW)]

**Total Voltage**

- Number of fiber pairs ($N_{FP}$)
- Feeding current (L,ROP,BW)
- Cable resistance
- Number of repeaters ($N_{REP}$)

Maximum Capacity per kV




Repeater Output Power (ROP), Span Length (L) and the number of fiber pairs (N) are free parameters defining total voltage entirely the Capacity optimization

✓ Fiber attenuation helps increasing span length (L), and reducing number of repeaters ($N_{REP}$)
✓ Lower cable resistance of cable, but costly ➔ Apply Aluminum??
✓ Repeater efficiency improvements reduce feeding current

# Example of line Design impact in powering

- Different line designs can provide the same capacity
- What is the best design in terms of power efficiency?

| | High SE design | Large FP count design |
|---|---|---|
| | | |
| Distance | 9000 | 9000 |
| Span Length | 75km | 100km |
| | | |
| Repeater sharing index | 4pumps/2FPs | 4pumps/4FPs |
| Repeater Power [dBm] | 19 | 15.1 |
| Line Current [mA] | 1000 | 750 |
| Resistance [Ohm/km] | 1.0 | 1.0 |
| Repeater BW [THz] | 4.5 | 4.5 |
| Fiber Effective Area | 150 | 110 |
| | | |
| OSNR/90carriers [dB] | 20.2 | 14.3 |
| GSNR [dB] | 11.9 | 7.3 |
| | | |
| Capacity Shannon FP [Tb/s]<br>*∝BWxlog2(1+GSNR)* | 34.8 | 23.2 |
| FPs | 8 | 12 |
| Capacity Shannon CABLE [Tb/s] | 278 | 278 |
| | | |
| Voltage Cable [kV] | 7.2 | 6.8 |
| Voltage Repeaters [kV] | 7.3 | 4.3 |
| Voltage Cable+Reps [kV] | 14.5 | 11.1 |

**Capacity grows logarithmically with SNR and linearity with BW**

**Large SNR comes with Fiber Nonlinearity**

**Power efficient submarine networks operate al low OSNR and larger bandwidth (more fibers)**

# Powering Topology

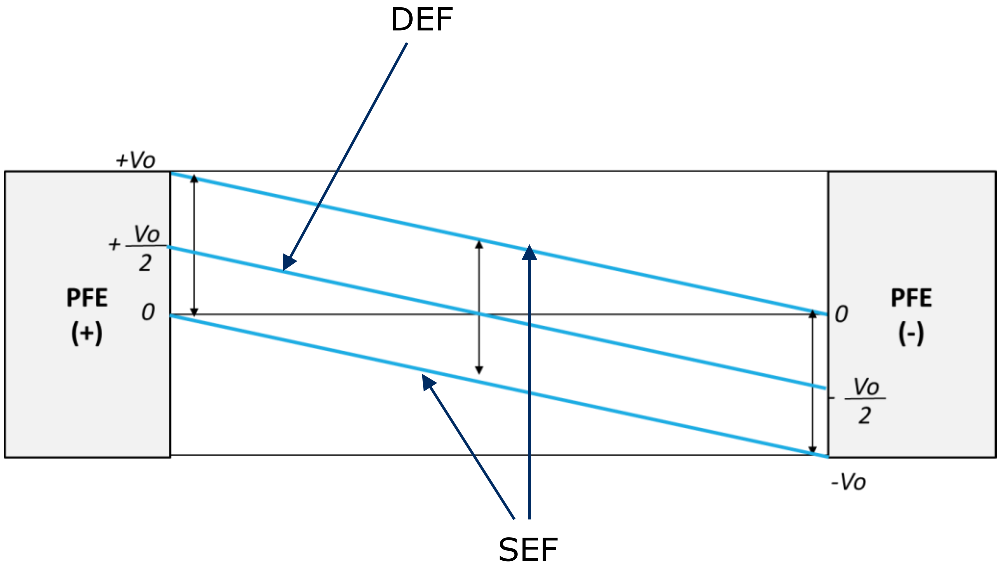
# Powering Mode

## Double-End-Feeding (DEF)

- Feeding power from both end station

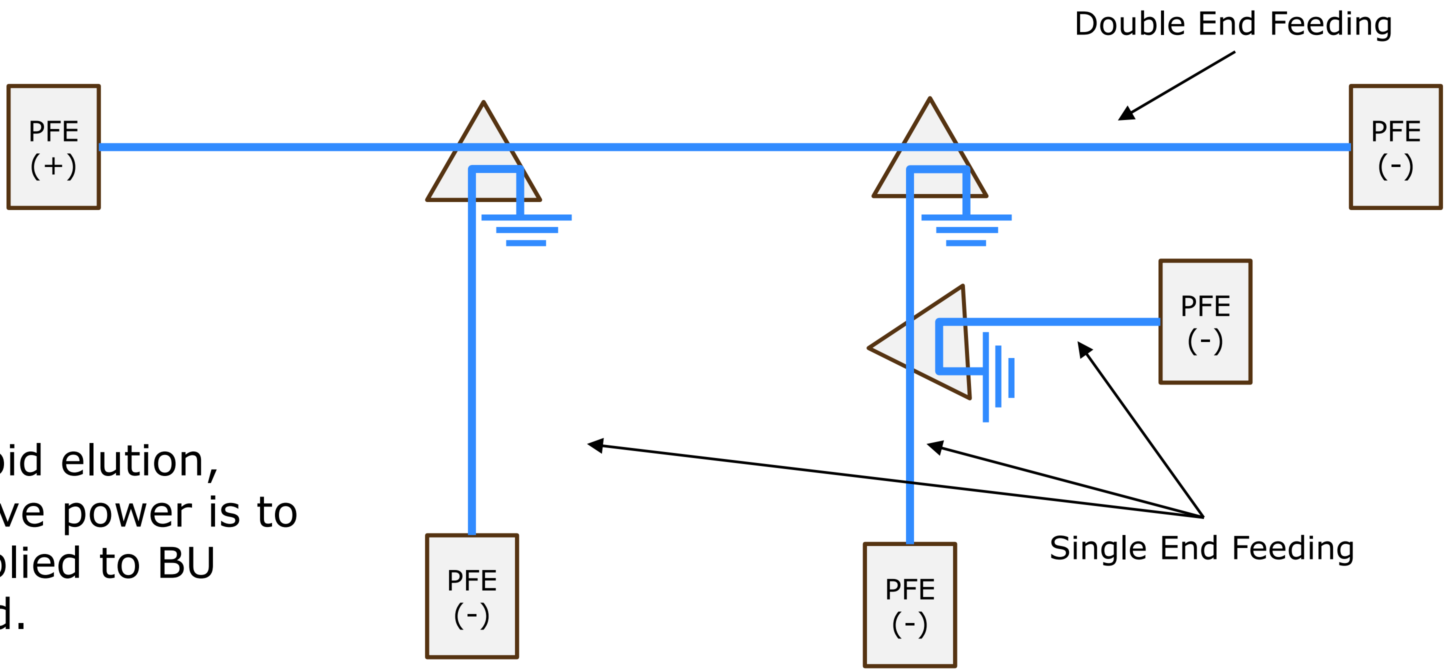
## Single-End-Feeding (SEF)

- Feeding power from one end station



# System Powering Example

- Trunk Segment : Double End Feeding
- Branch Segment : Single End Feeding




Note;

To avoid elution, negative power is to be applied to BU ground.

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# Power Feeding Equipment (PFE)

# Power Feeding Equipment (1/4)

## Major Functions

- Current control
  - Precise current control is required for stable system
- Polarity switching (when PSBU is deployed)
  - Polarity change is required for power re-configuration (detail to be discussed in Part III.)
- Voltage limitation
  - To avoid voltage generation beyond a specific value, the maximum output voltage is limited.
- Slow ramp up & down
  - To avoid large surge currents being injected into the line, the PFE controls the voltage ramp-up and ramp-down speeds.

# Power Feeding Equipment (2/4)

## Major Functions (cont.)

- Shutdown function
  - Auto-shutdown when high current, high voltage, and/or open circuit is detected
  - Auto-shutdown when operator access high voltage terminal
  - Emergency shutdown is provided for the event of an accident or other potential hazard

- Discharge function
  - Cable end stores electric charge due to cable capacitance
  - PFE provides discharge function
    - Resistive Mode
    - Short Mode

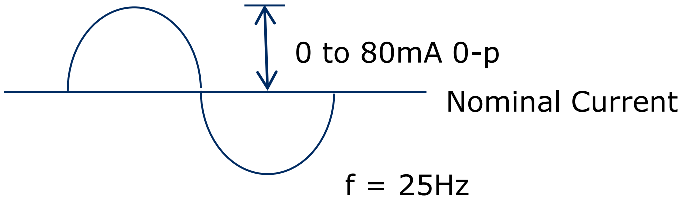
# Power Feeding Equipment (3/4)

## Major Functions (cont.)

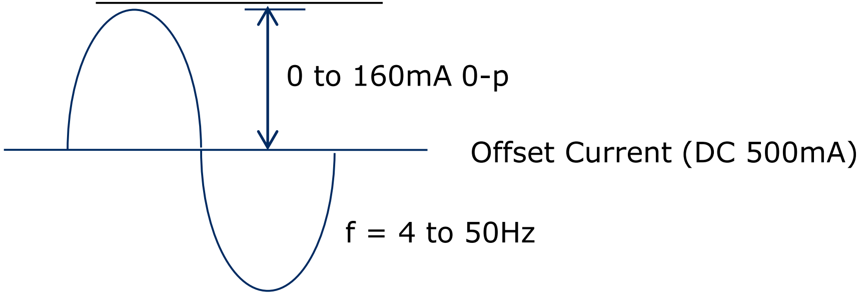
- Electroding
  - ✓ This function is used to identify the cable or cable fault location by cable ship
  - ✓ Electroding tone is detected by tone detector (magnetic sensor) equipped on cable ship

  - Electroding tone (low frequency) is superposed on a nominal current or DC offset current

In-service Mode



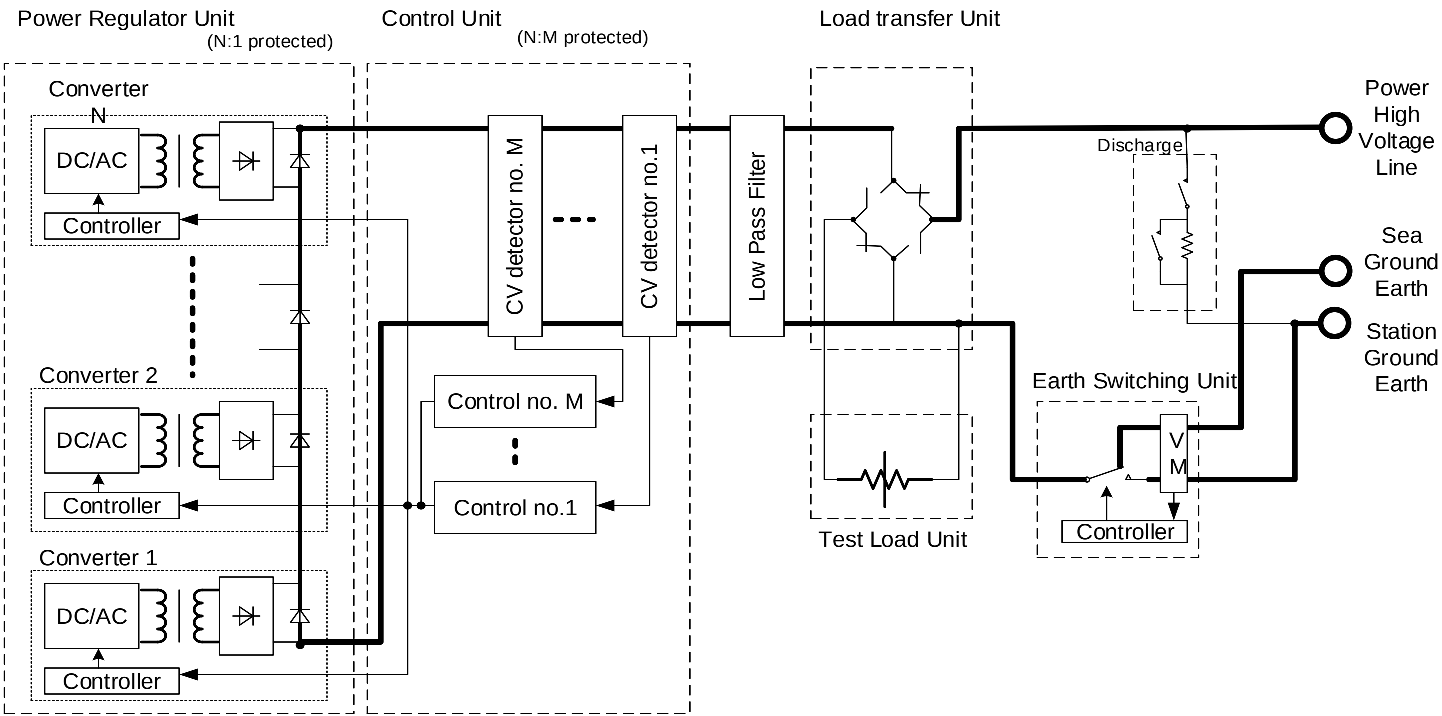

Out-of-service Mode




Electroding tone of 10mA can be detected;
- 300 km from PFE (In-service mode)
- 500 km from PFE (Out-of-service mode)

# Power Feeding Equipment (4/4)

## Configuration



# Power Path Switchable BU (PSBU)

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# Powering Switchable - Branching Unit (PSBU)

## Branching Unit (BU)

- BU is laid underwater for the trunk and branch system
- BU provides routing both optical fiber and power feeding path to trunk and branch landing stations
- PSBU ➔ Power path switchable BU

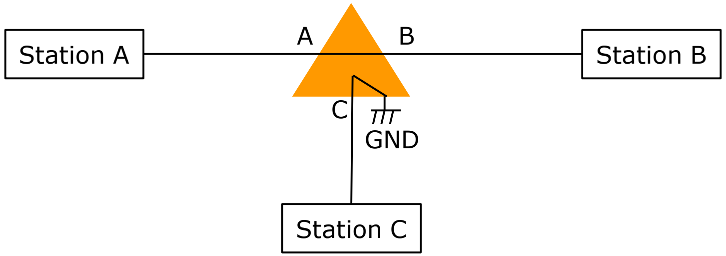
## Key Features for Power Feeding Routing

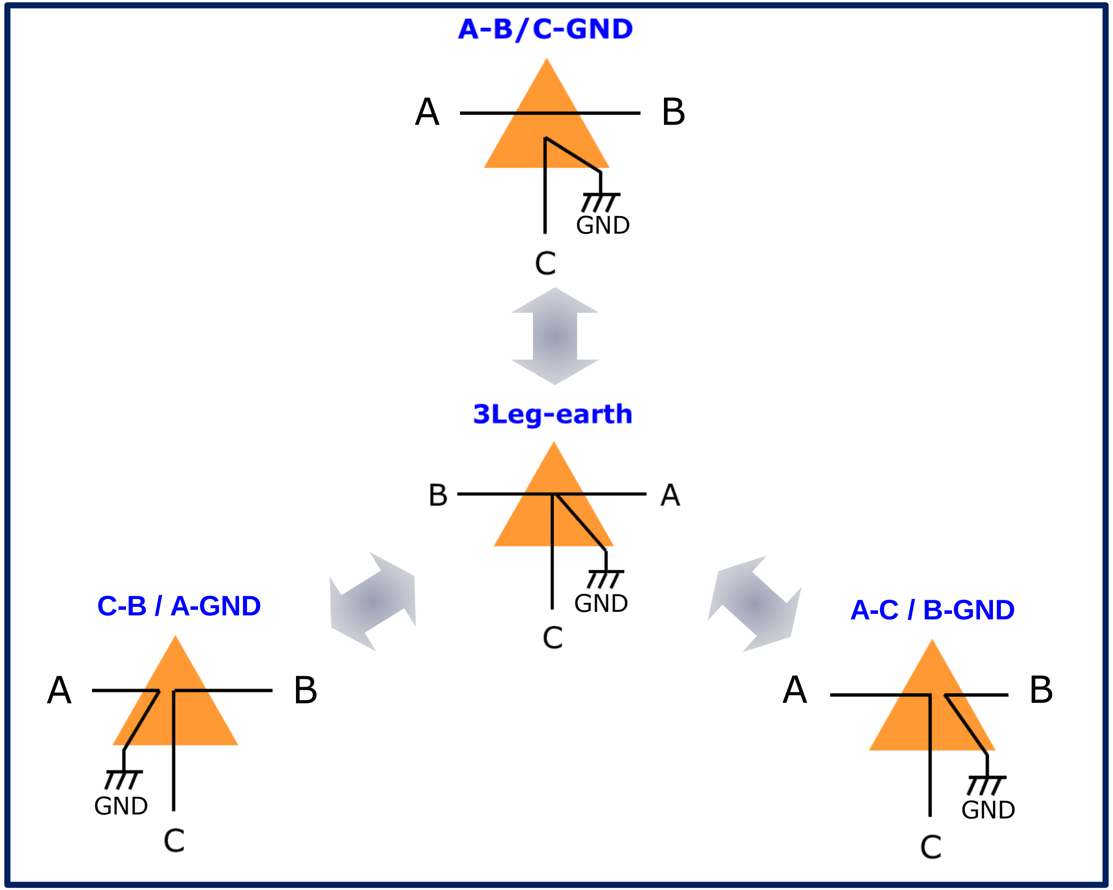
- Reconfiguration of PSBU status shall be performed by optical command
- Command operation shall be available as long as BU is powered any one of three leg, even branch power only
- Switch status is maintained even if the electric power is removed from the BU.
- “Hot switching” is feasible under single-end feeding ➔ Withstand up to 15KV

# Powering Switchable - Branching Unit (PSBU)

## Switch Status

Normal Configuration

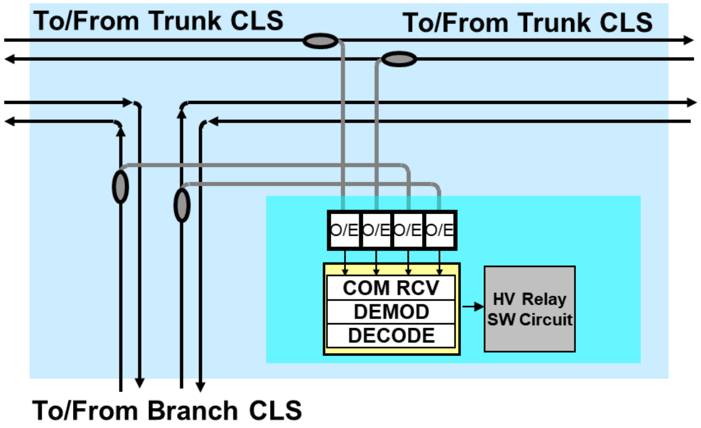


# Powering Switchable - Branching Unit (PSBU)

## Remote Control of PSBU

- High Voltage Circuit
  - Highly reliable SW part
- Command Control of BU Switch
  - Control Command to be sent as serial data including BU address
  - Only the BU assigned by the address responds to the command signal
- Multi Control Path
  - BU can be controlled through multiple fiber paths
- Self Holding
  - BU power path status configured by the command maintains even when power supply stops



# Submarine Cable

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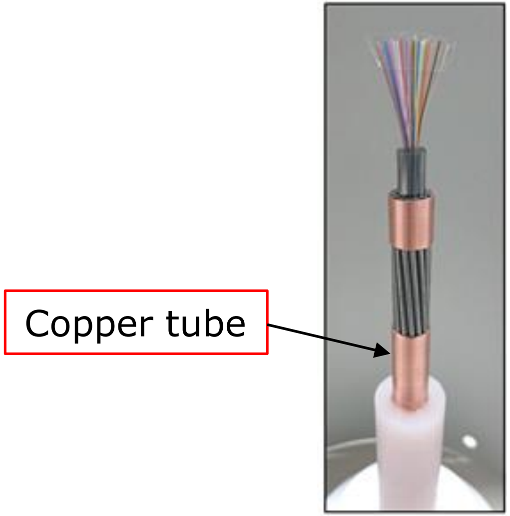
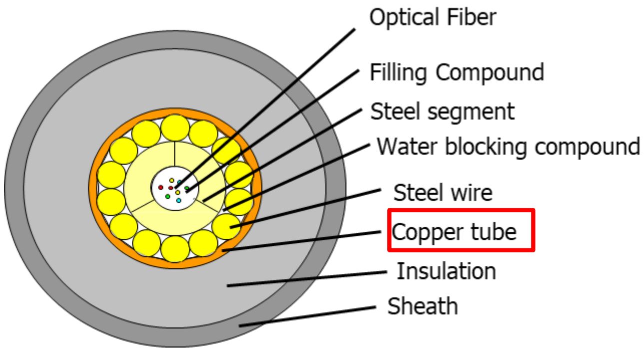
# Submarine Cable Structure

- ✓ Power is fed through copper tube in submarine cable
- ✓ Cable resistance is depending on thickness of copper




LW (Light Weight)

# Contents

# System Powering and Redundancy

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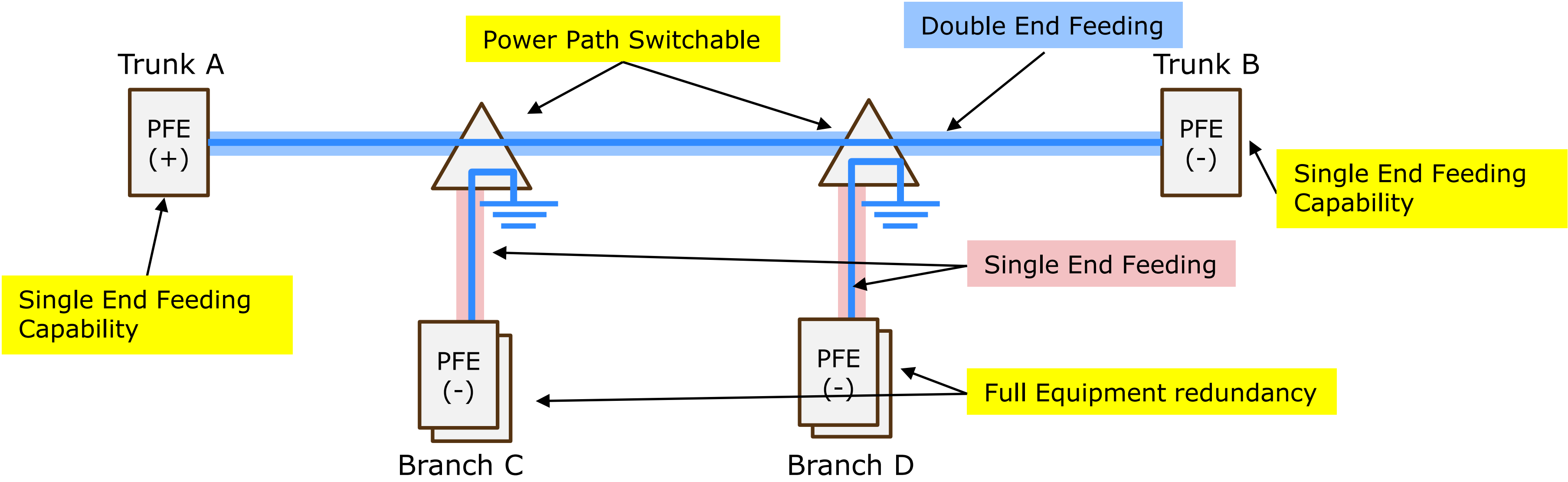
# Normal Power Feeding Configuration

## Features:

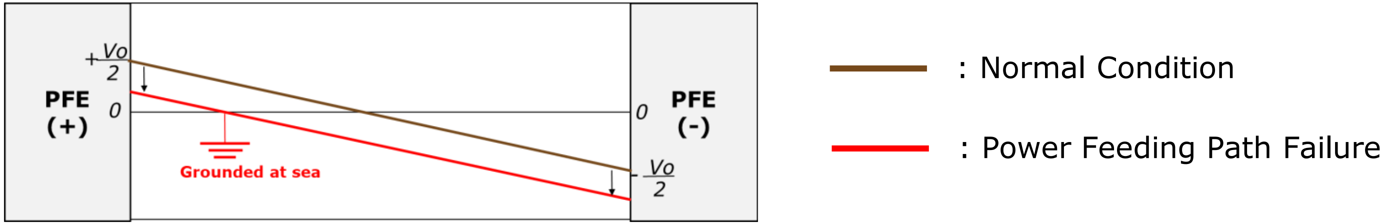
- Trunk Double End Feeding with Single End Feeding capability
- Branch :  Full Equipment Redundancy
- BU : Power Path Re-configurable



# System Redundancy

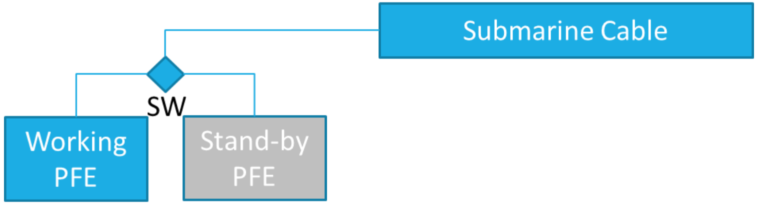
## Trunk Power Feeding Path with Single End Feeding Capability

- Maintain power even if power path failure happens




## Equipment Redundancy

- Full Equipment Redundancy

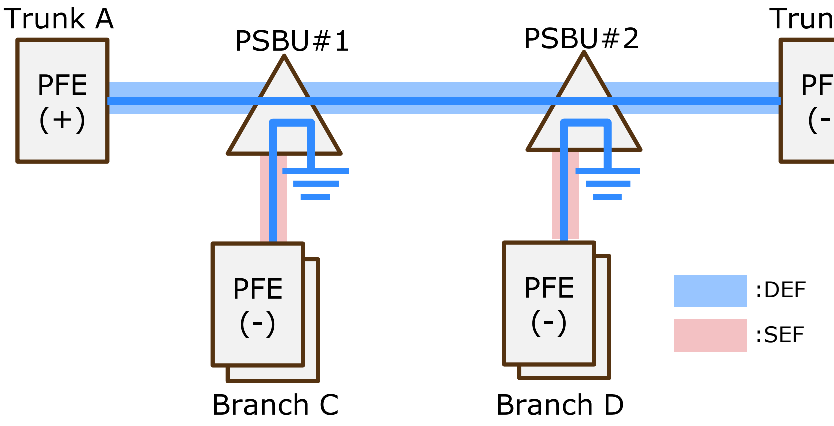



## Power Path Switching

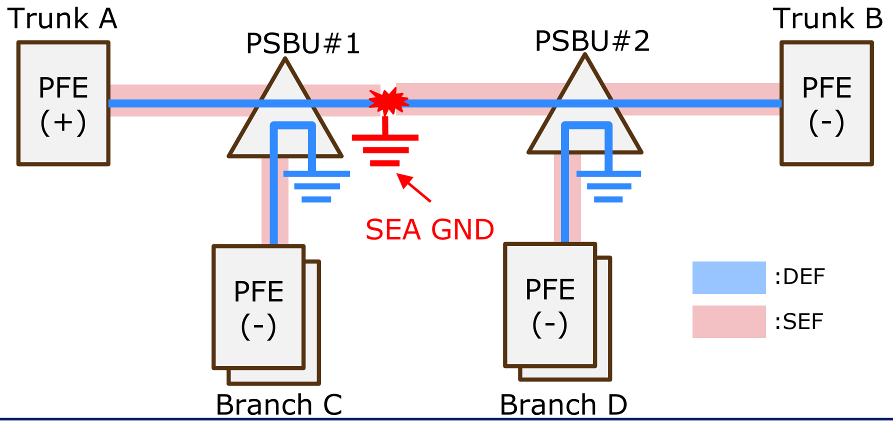
- Power Path Switching to restore power feeding path for un-failed segment

# Power Path Re-Configuration

# Power Feeding Path Re-Configuration -Trunk Failure (1/3)



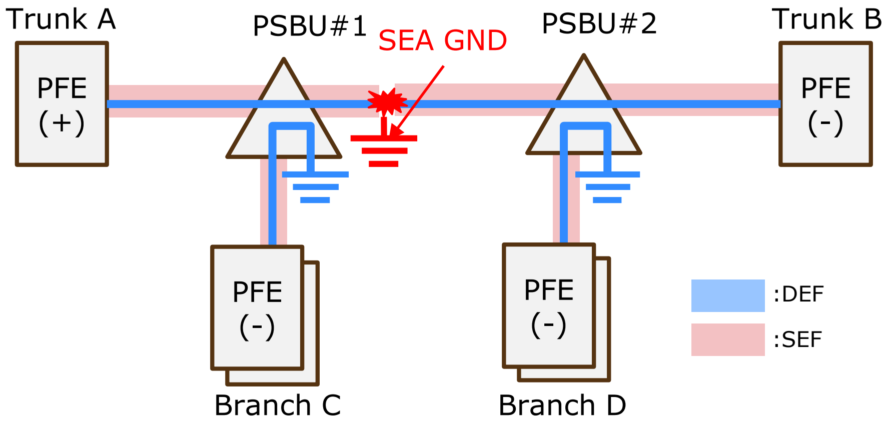

## Normal Configuration



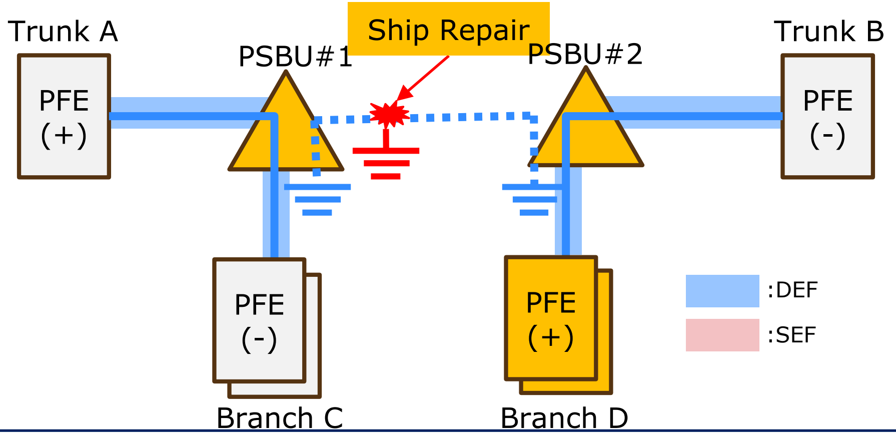

## After trunk path failure

- ✓ Power feeding is **maintained** since PFEs in Trunk A and B feed power to sea ground under SEF
- ✓ Power re-configuration is not required until ship repair

# Power Feeding Path Re-Configuration -Trunk Failure (2/3)




## After trunk path failure



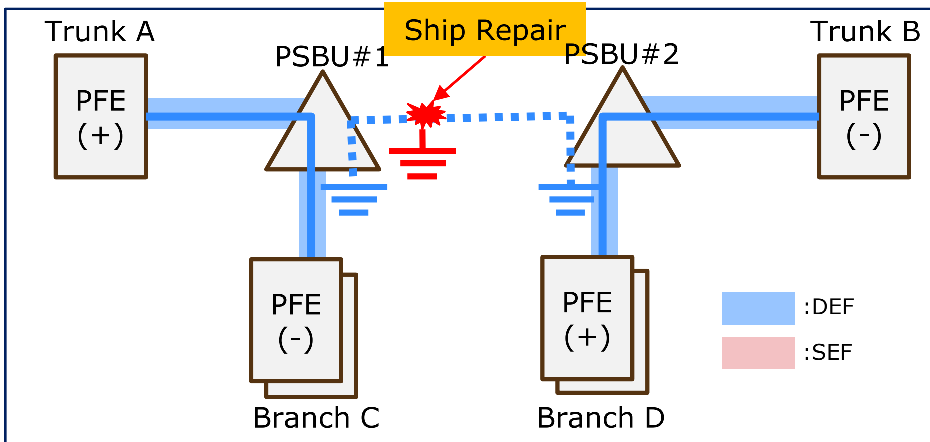

## During Ship Repair

✓ Powering path is **re-configured** in order to isolate failure segment;

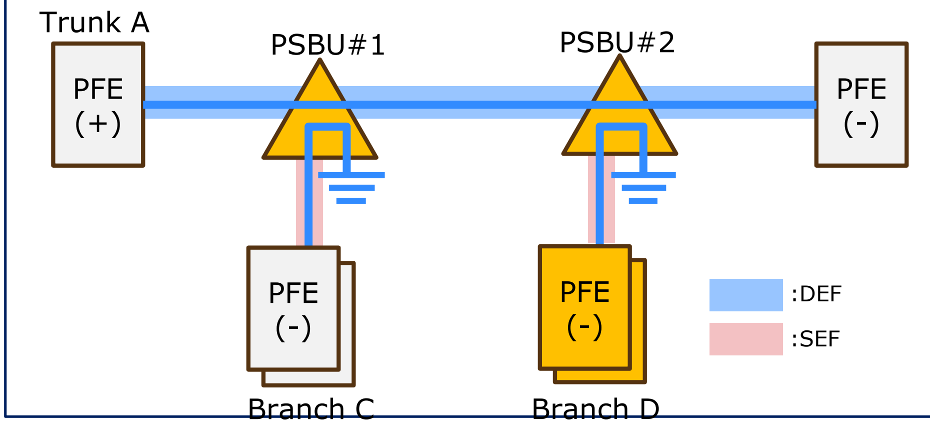
- Trunk A – Branch C (DEF)
- Trunk B – Branch D (DEF)

- PSBU#1 and #2 are switched
- Branch D polarity is changed

# Power Feeding Path Re-Configuration -Trunk Failure (3/3)




## During Ship Repair




## After Ship Repair

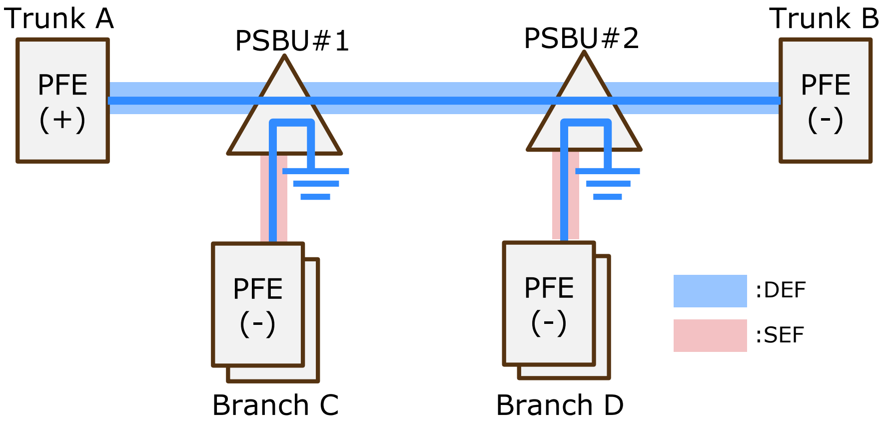
✓ Powering path is **normalized:**

- Trunk A – Trunk B (DEF)
- PSBU#1 – Branch C (SEF)
- PSBU#2 – Branch D (SEF)

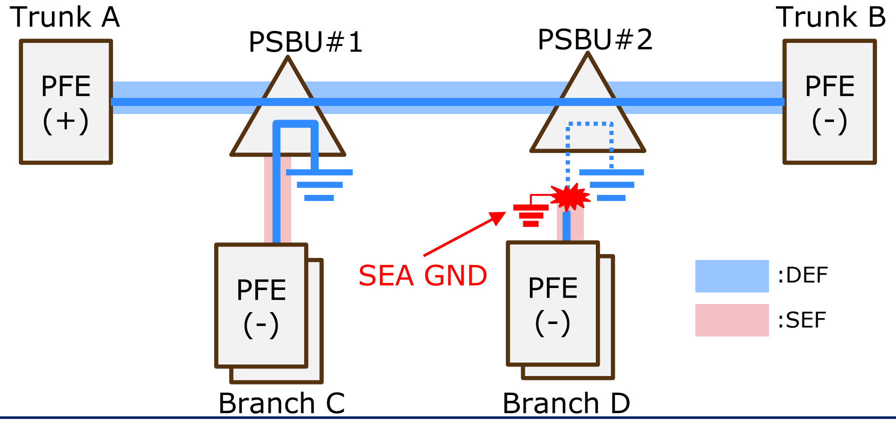
- PSBU#1 and #2 are switched
- Branch D polarity is changed

# Power Feeding Path Re-Configuration -Branch Failure (1/4)

## Normal Configuration



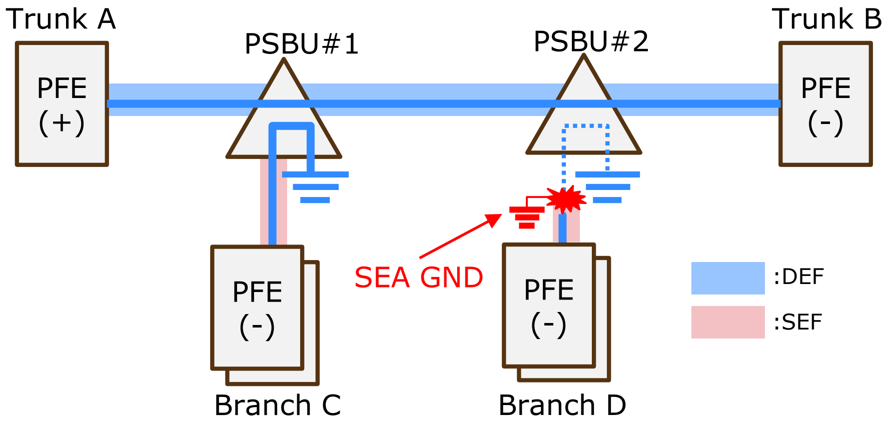

## After branch path failure



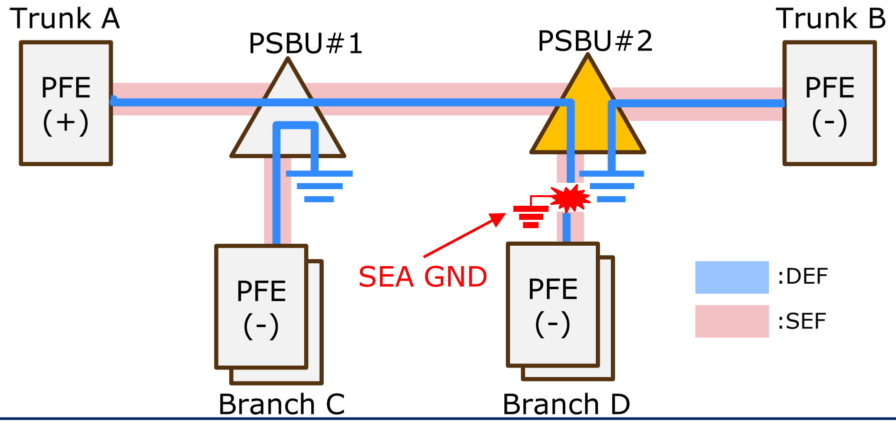

✓ PSBU#2 and failure point becomes **unpowered**.

✓ Un-failed segment does **not affected**.
- Trunk A-B,
- PSBU#1-Branch C

# Power Feeding Path Re-Configuration -Branch Failure (2/4)




## After branch path failure




## Before Ship Repair

✓ Power path is **re-configured** in order for failure segment to be **restored**.

- Trunk A- Branch D fault Point (SEF)
- Trunk B- PSBU#2 GND (SEF)
- Branch C – PSBU#1 (SEF)
- Branch D – Failure point (SEF)

○ PSBU#2 is switched



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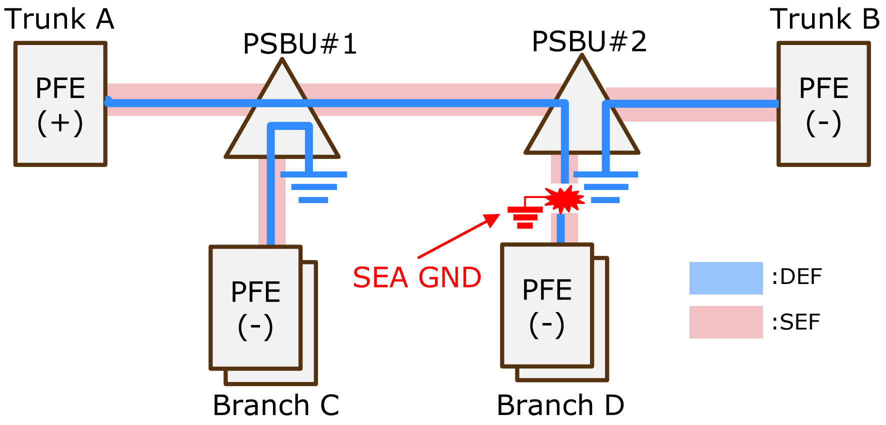
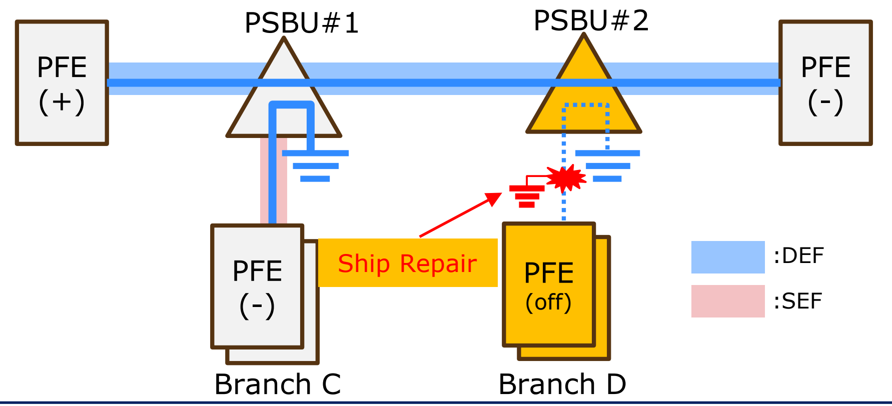
# Power Feeding Path Re-Configuration -Branch Failure (3/4)




## Before Ship Repair




## During Ship Repair

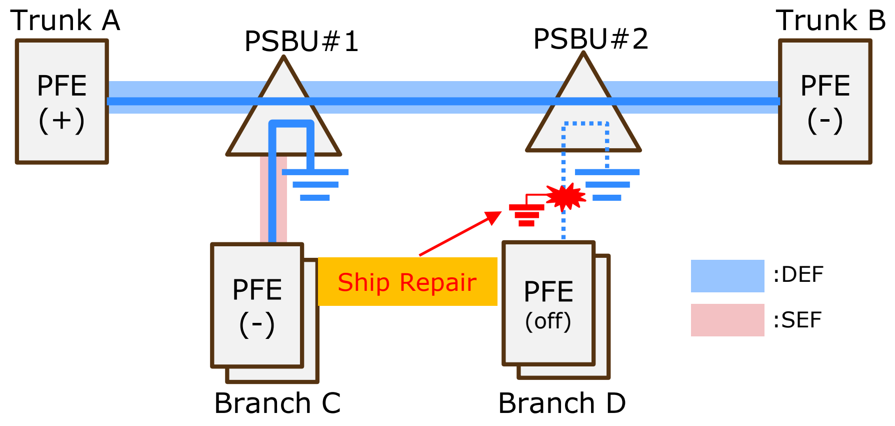
✓ Power path is **re-configured** in order to **isolate** failure segment;

- Trunk A- B (DEF)
- Trunk B- PSBU#2 GND (SEF)
- Branch C – off

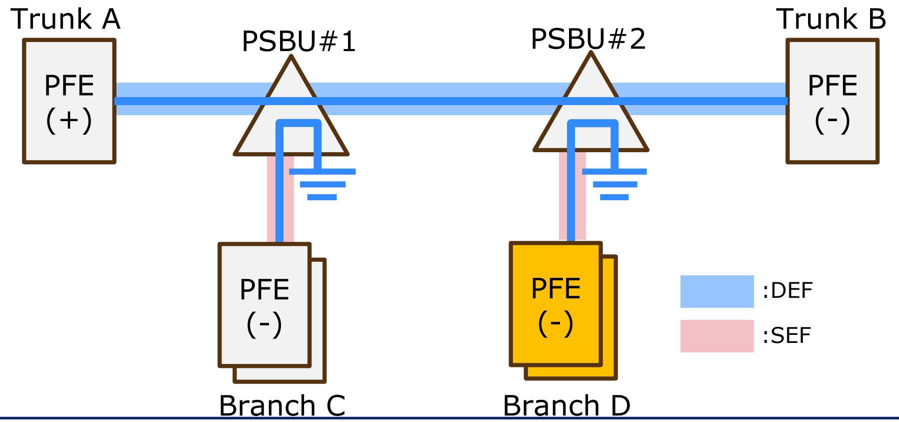
○ PSBU#2 is switched

# Power Feeding Path Re-Configuration -Branch Failure (4/4)

## During Ship Repair




## After Ship Repair




✓ Powering path is **normalized:**
- Trunk A – Trunk B (DEF)
- PSBU#1 – Branch C (SEF)
- PSBU#2 – Branch D (SEF)

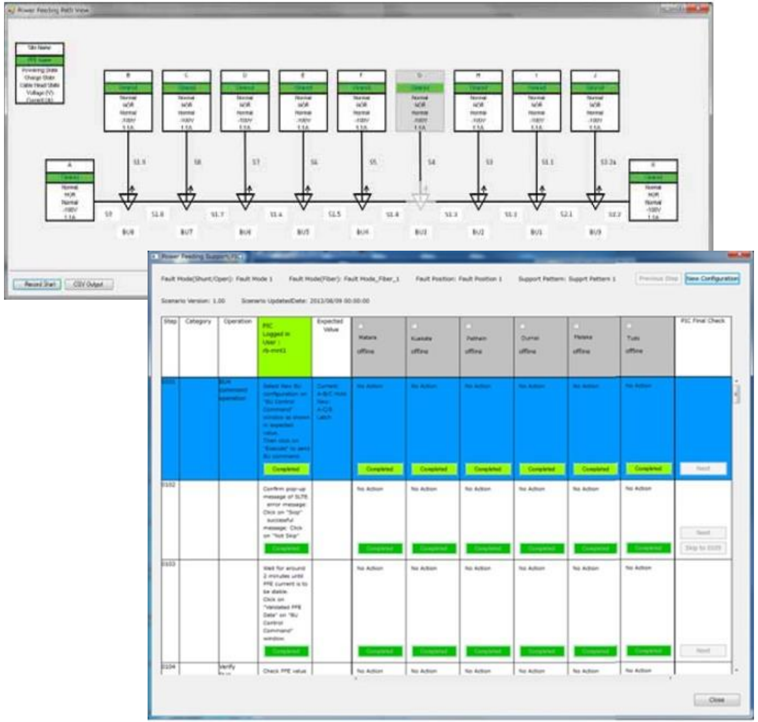
○ Branch D is just powered

# Powering Management System

# Power Feeding Management System

## Functions

- Monitor power feeding current and voltage for every station
- Manage PFE status
- Control and manage Power-Path Switching in BU
- Display the power feeding configuration
- Support powering procedure among stations



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