Cable Powering

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NEC Corporation
I. Powering Method
   a. Powering Method
   b. Powering Design
   c. Powering Topology

II. Equipment for Powering
   a. Power Feeding Equipment (PFE)
   b. Power Path Switchable BU (PSBU)
   c. Submarine Cable

III. System Powering & Reconfiguration
   a. System Powering and Redundancy
   b. Power Path Re-configuration
   c. Powering Management System
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Powering Method
Purpose of Powering Feeding

To supply stable power to submersible repeaters

General Requirement:
- 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...
Direct Current and Series Circuit are applied for all submarine cable system
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

\[ \text{Constant} = V^{nt} \]

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

\[
V_{\text{SYSTEM}} = V_{\text{EARTH_GROUND}} + V_{\text{EATH_CABLE}} + V_{\text{PFE}} + V_{\text{LAND_CABLE}} + V_{\text{SUB_PLANT}} + V_{\text{SUB_CABLE}} + V_{\text{EPD}} + V_{\text{REPAIR}}
\]

where,

- \(V_{\text{SUB_CABLE}} = \text{Cable Resistance} \times \text{Cable Length} \times \text{Feeding Current}\)
- \(V_{\text{SUB_PRANT}} = \sum V_{\text{REP}} + \sum V_{\text{BU}}\)
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

<table>
<thead>
<tr>
<th>Current distribution in a repeater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>LD current for the specified optical output power</td>
</tr>
<tr>
<td>Current for LD control circuit</td>
</tr>
<tr>
<td>Electroding margin</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>System</th>
<th>Link Length (km)</th>
<th>a) Calculation</th>
<th>b) Measured</th>
<th>c) Earth Potential Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan-Guam</td>
<td>3,743</td>
<td>4,404</td>
<td>4,352</td>
<td>-52</td>
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<tr>
<td>Guam-Australia</td>
<td>7,130</td>
<td>7,296</td>
<td>7,189</td>
<td>-107</td>
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<tr>
<td>Malaysia-China</td>
<td>2,632</td>
<td>4,339</td>
<td>4,469</td>
<td>130</td>
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<td>Singapore-Phillippin</td>
<td>2,789</td>
<td>4,073</td>
<td>4,208</td>
<td>135</td>
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<tr>
<td>Japan-Taiwan</td>
<td>2,792</td>
<td>4,617</td>
<td>4,646</td>
<td>29</td>
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</tbody>
</table>

Repair Allowance

- Design life of 25 years, 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 ($N_{REP}$)

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?

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

*Capacity grows logarithmically with SNR and linearity with BW*

**Large SNR comes with Fiber Nonlinearity**

Power efficient submarine networks operate at 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.
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
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

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

Power Regulator Unit (N:1 protected)

Converter

DC/AC

Controller

Converter 2

DC/AC

Controller

Converter 1

DC/AC

Controller

Control Unit (N:M protected)

CV detector no. M

CV detector no. M

Low Pass Filter

Load transfer Unit

Load transfer Unit

Test Load Unit

Earth Switching Unit

Power High Voltage Line

Sea Ground Earth

Station Ground Earth

Control Unit

Control no. M

Control no. M

Control no. 1

Control no. 1

DC/AC

Controller

Low Pass Filter

Load transfer Unit

Test Load Unit

Earth Switching Unit

Power High Voltage Line

Sea Ground Earth

Station Ground Earth
Power Path Switchable BU (PSBU)
Branding 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

Station A

Station B

Station C

A

B

C

A-B/C-GND

3Leg-earth

C-B / A-GND

A-C / B-GND
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
Submarine Cable Structure

- Power is fed through copper tube in submarine cable
- Cable resistance is depending on thickness of copper
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System Powering and Redundancy
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**

- 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.

**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**

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

**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**

- 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

- **Trunk A**: PFE (+) to PSBU#1 to Branch C to PSBU#2 to Trunk B
- **Trunk B**: PFE (-)

#### Before Ship Repair

- **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
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**

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

**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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