SUBSEA CONTROLS
DOWN UNDER 2022

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CATASTROPHIC FAILURES IN LONG UMBILICALS

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WHO WE ARE & WHAT WE DO

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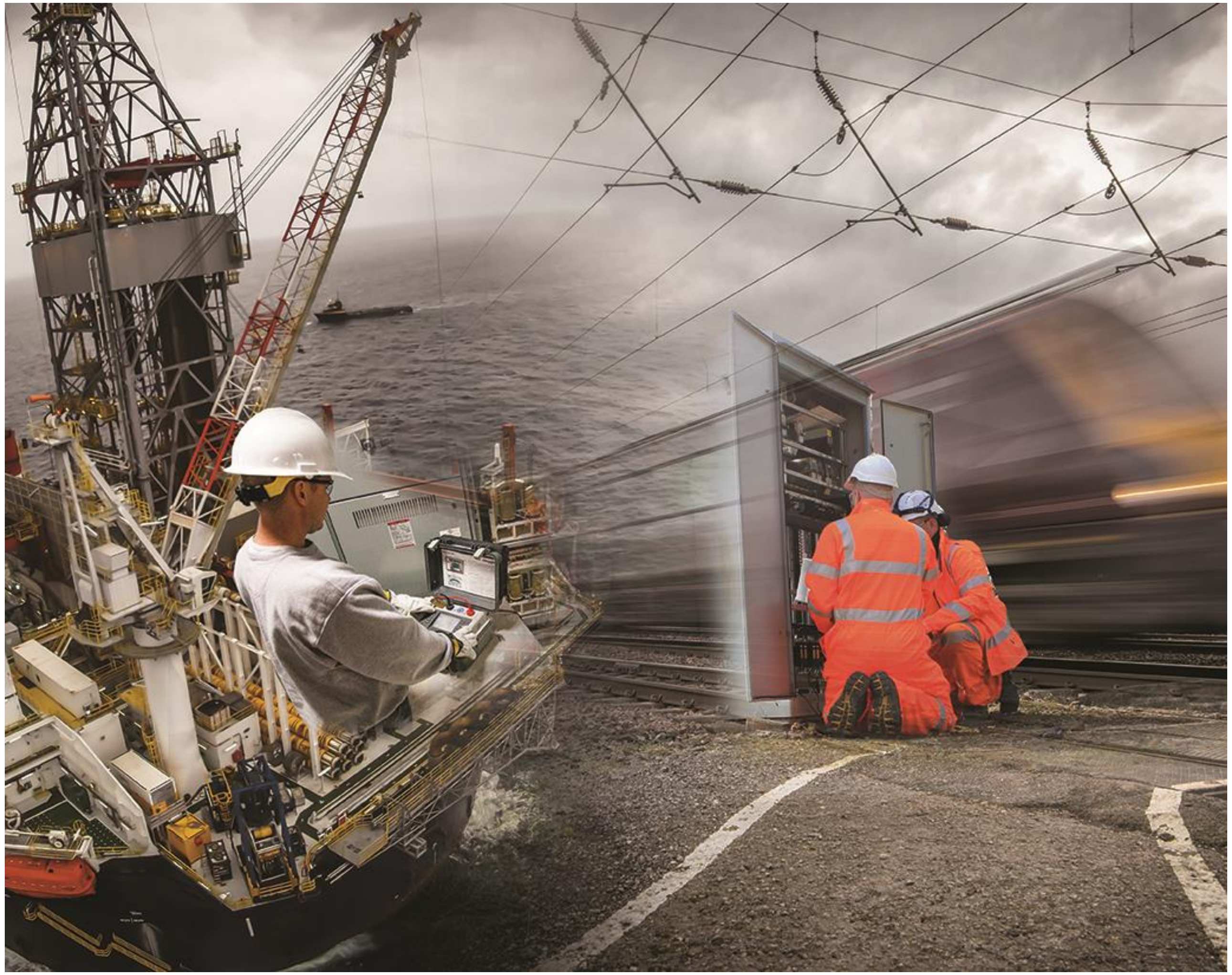

Subsea Insulation Resistance Monitoring & Recovery

V-LIFE®

Online Electrical Cable Integrity Monitoring & Fault Finding

V-LIM®

V-IR®

CABLE GUARDIAN®

POWER DISTRIBUTION SYSTEMS

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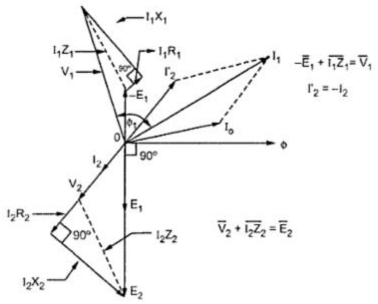
Three main considerations:



AC or DC	Single or Multi Phase	Earthing

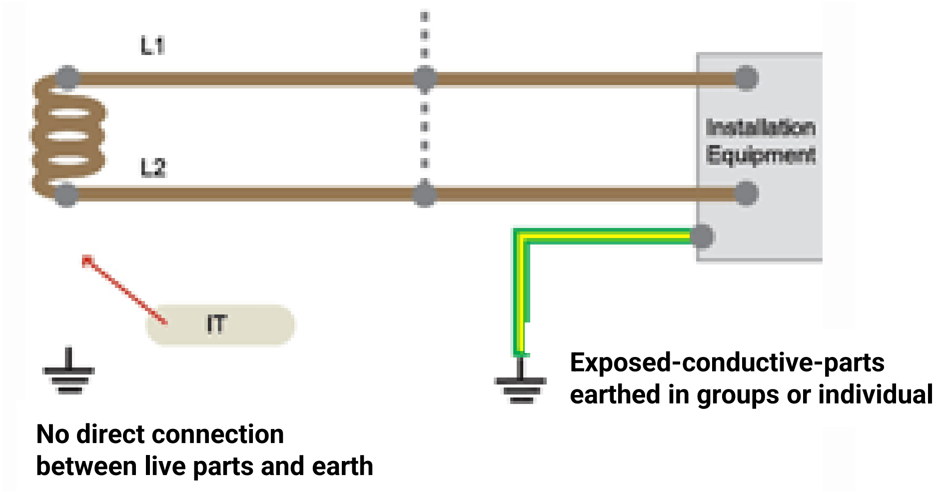
- Most subsea control systems utilise:
  Single phase, AC, ungrounded IT systems operating at <3000V
- Three phase systems have been used for long offset subsea controls
  Always ungrounded IT systems
- DC supplies are predominantly used in Subsea Controls by Schlumberger/OneSubsea

IT (ISOLATION TERRA) SYSTEMS

- IT systems have no deliberate electrical connection to earth and are fault tolerant.

Traditional understanding and normal practice:

- Continued supply on first ground fault
- Ground current on a first fault is very small



IT System

CASE STUDY – A CONFLICT WITH THEORY?

The Facts:

1. An EPU tripped due to an over-current during a first earth-fault condition.

2. The fault was verified as a short-circuit to ground in a connector.

3. The umbilical was long (>100km)

Hopefully you will see that we will be questioning "the traditional understanding"

- **Why** did this occur?
- **What** caused the over-current?

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FAULT CHARACTERISTICS AT EPU

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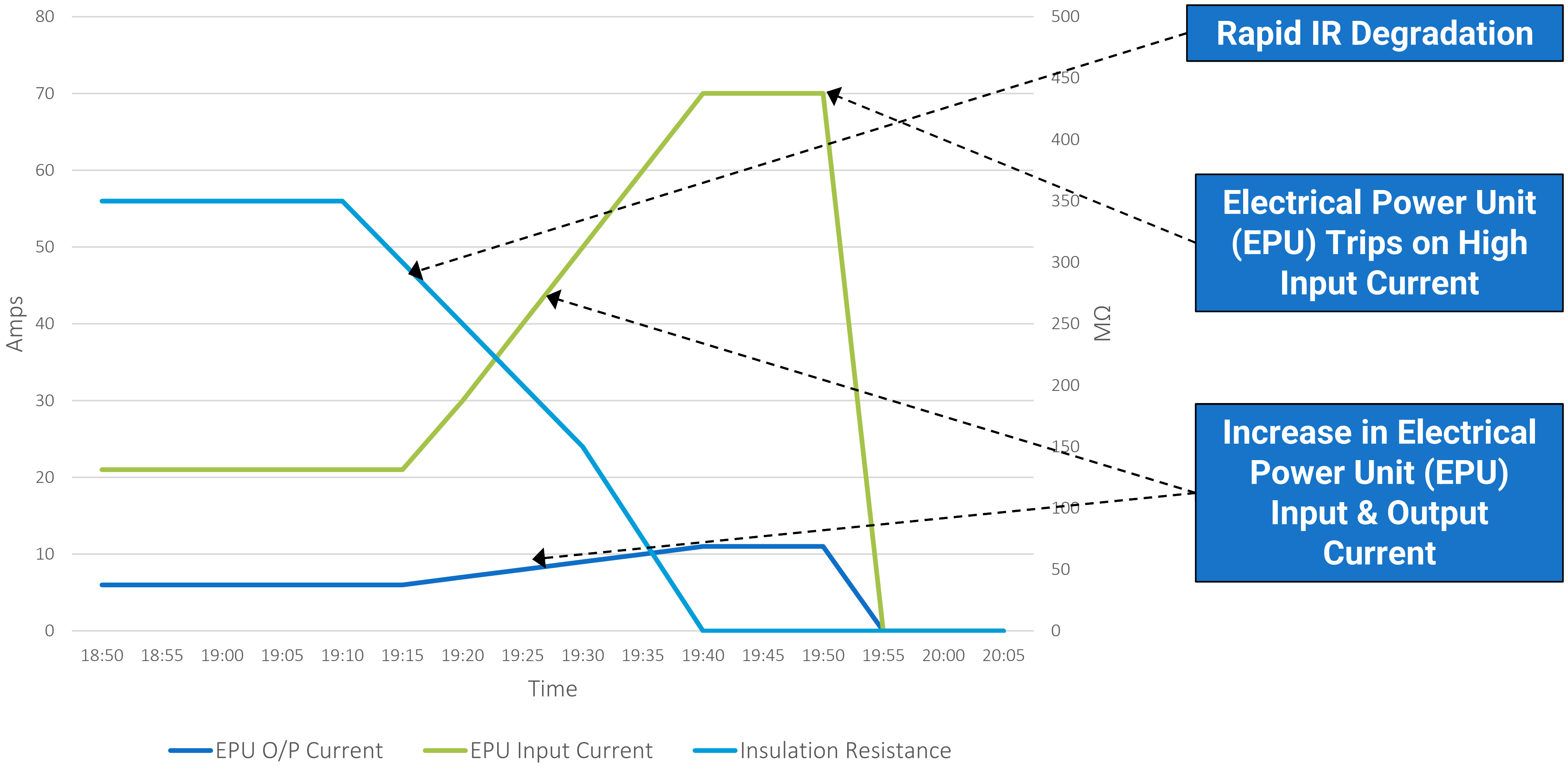
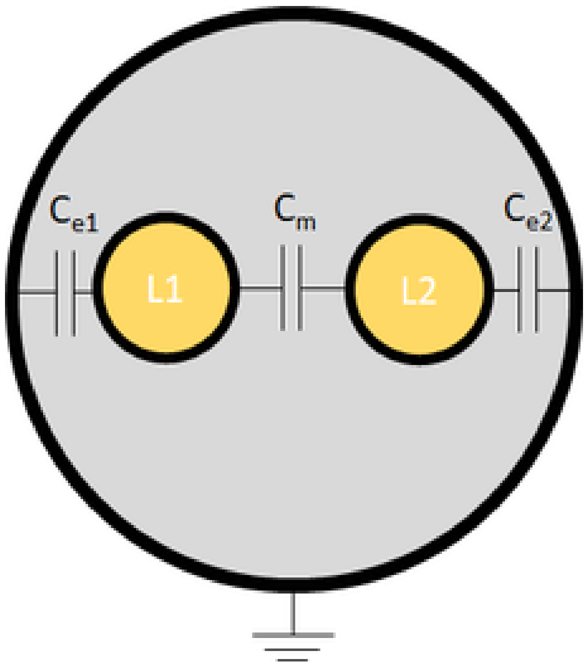
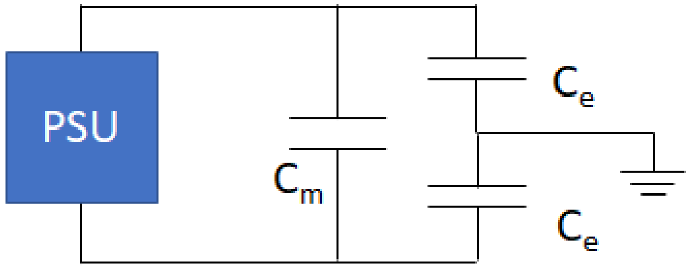


LINE CAPACITANCE

Charging current is an unwanted effect in any AC transmission line and occurs due to the inherent capacitance between conductors, and between the conductors and ground.





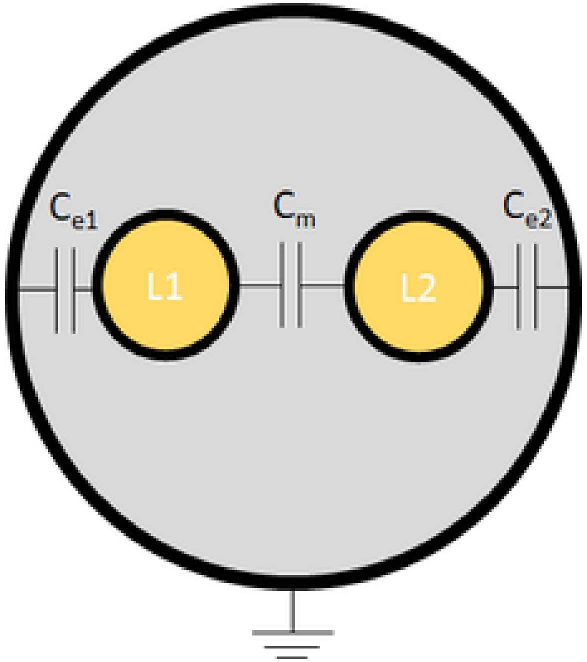
$$C = C_m + C_e/2$$

For a general twin core cable the **earth capacitance** (C_e) is approximately twice that of the **mutual capacitance** (C_m) between the conductors.

CABLE GEOMETRIES & CAPACITANCE

A quoted line Capacitance (C) of 60nF comprises of:

C_m = 30nF
C_e = 60nF



For a given voltage rating, an increase in the conductor CSA (Cross Sectional Area) will generally result in an increase in the specified Capacitance per unit length.

For a given cross section, an increase in the voltage rating will generally result in a reduction in the specified Capacitance per unit length.

AC TRANSMISSION & CAPACITANCE

In subsea systems where cable capacitance is high, it dominates the transmission characteristics.

Cable manufacturers usually specify the cable capacitance per unit length (for long cables, this is usually in nF/km). **Charging current is directly proportional** to both the cable length and the line voltage.

The charging current for a 100km umbilical with a specified line capacitance (C) of 60nF/km operating at 3.0kV (V) is around 5.6A in normal operating conditions, **independent of any load being connected.**

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AC TRANSMISSION

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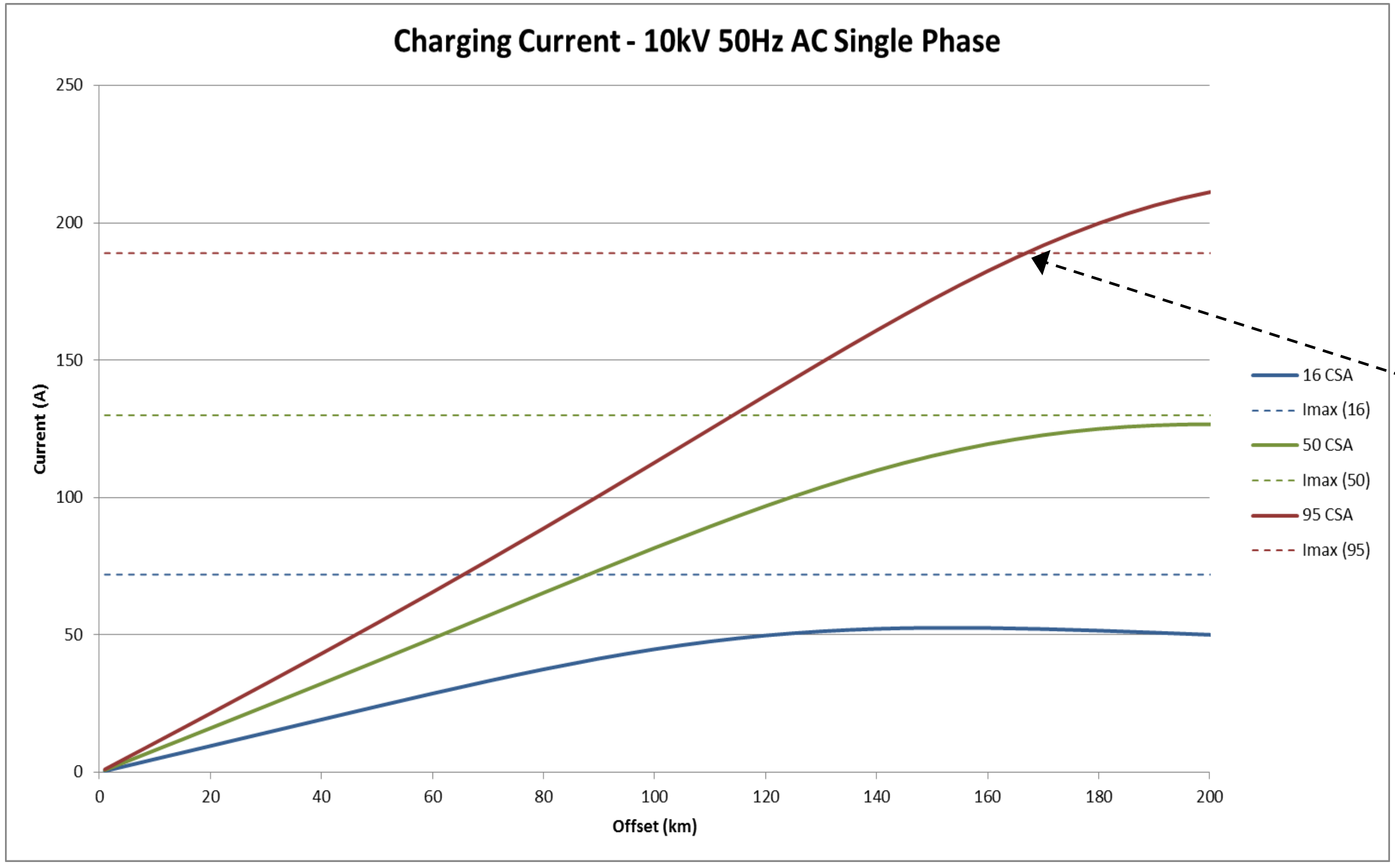
Capacitance is generally the ultimate restriction in the length of AC power transmission systems, as in long transmission lines the charging current can exceed the cables maximum current carrying capacity**.**



Charging current can exceed the cables maximum current carrying capacity

POWER FACTOR CORRECTION

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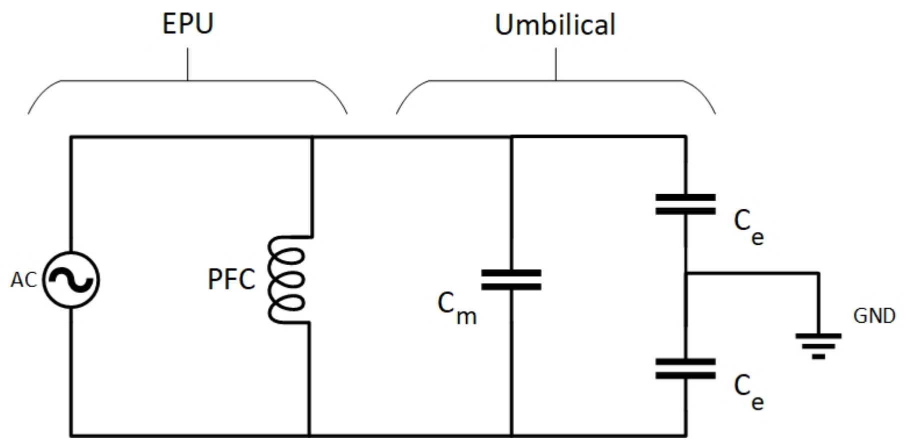
In order to reduce the impact of the cable charging current on the electrical power unit, some systems will **employ an inductor** (which is a type of energy storage device) connected across the line conductors (L1 & L2) for the purposes of power factor correction.

The impact of adding the inductor is a (simulated) reduction on the load capability requirements of the power supply of around 55% during normal operating conditions.



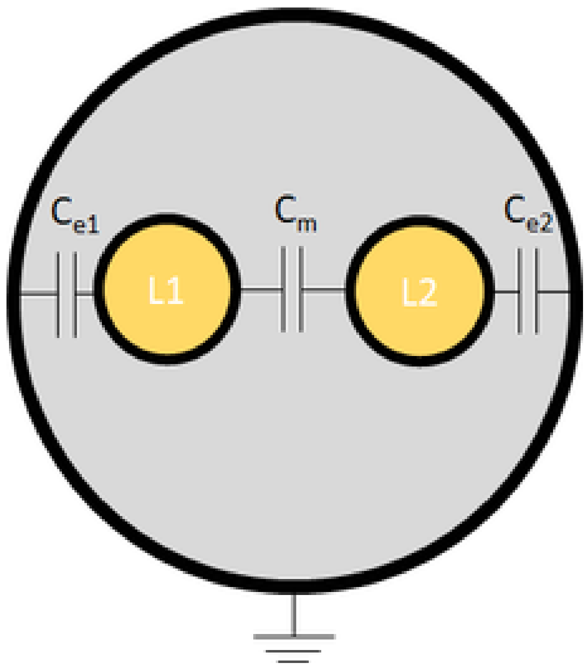
Resonant Circuit

MORE URBAN MYTHS

- **Traditional / common assumptions for power delivery:**
  - Increase in voltage will increase offset capability
  - Increase in Cross Sectional Area will increase offset capability
  - Increase in voltage will improve efficiency
  - Increase in Cross Sectional Area will improve efficiency
- Definitely true for DC systems **but AC systems are far more complex**

SINGLE EARTH FAULT

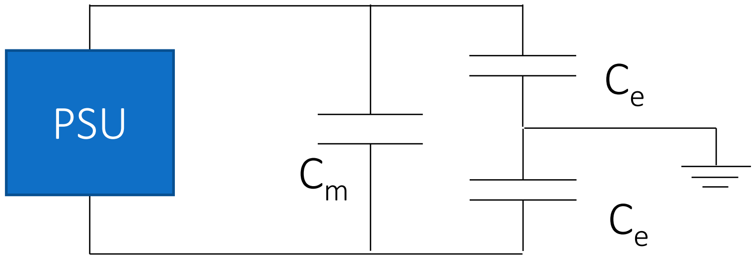
If series resistance, inductance and resistive leakages are not significant.



Due to cable physical dimensions, $C_e \approx 2C_m$

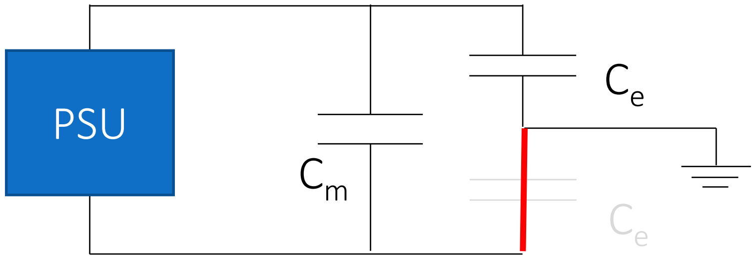
Under Normal Operation

Total Capacitance "seen" by EPU due to cabling;
$= C_m + C_e/2$



Single Earth Fault

Total Capacitance
$= C_m + C_e$



Consequences:

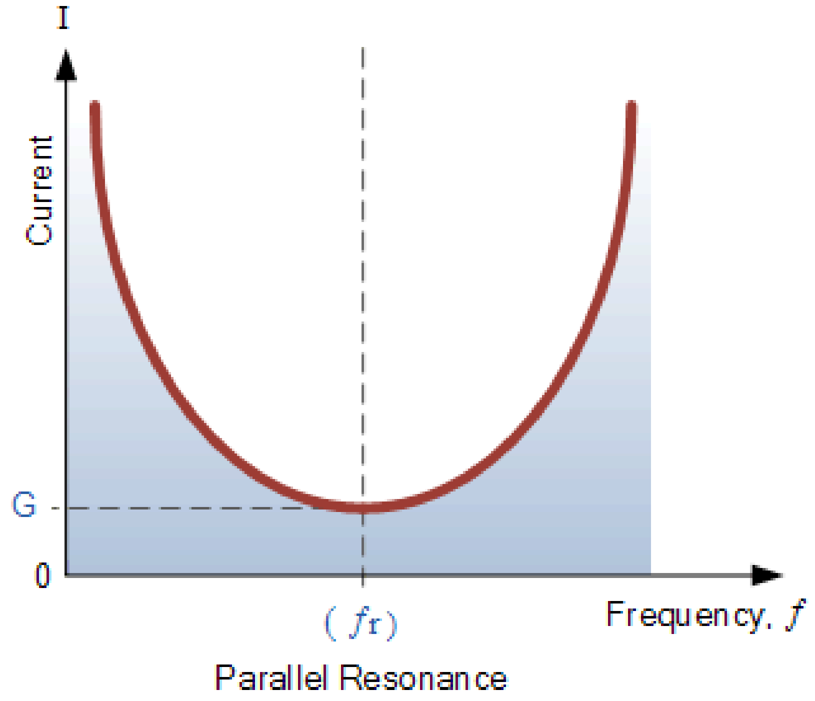
1. Under Single Earth Fault conditions, capacitance "seen" by EPU increases ≈ 50%. **EPU load current increases** proportionally.
2. In addition, the fixed topside PFC correction no longer functions as desired. **Total EPU current increases.**
3. EPU overcurrent protection triggered.

POWER FACTOR CORRECTION

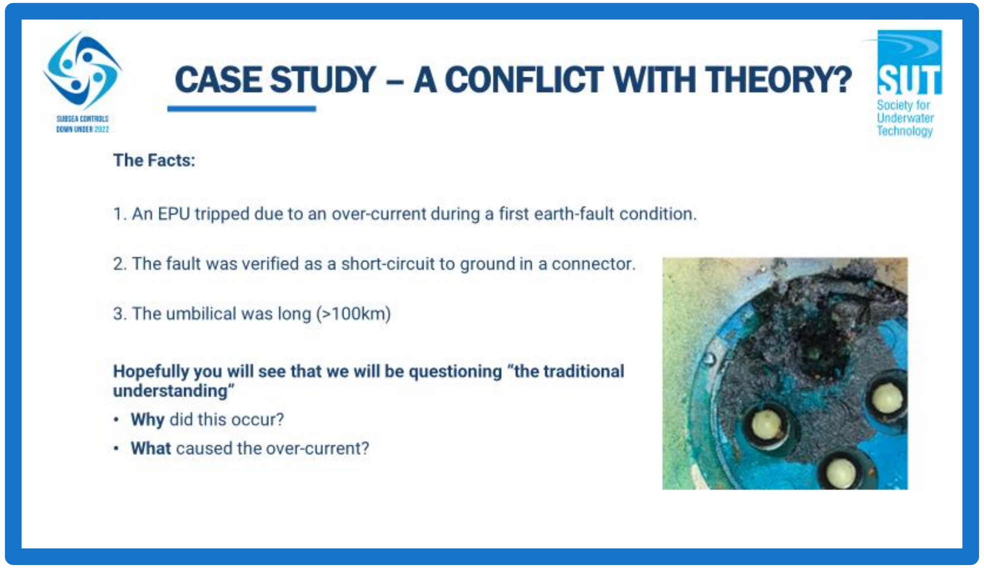
While this works very well during normal operation, during a single fault condition the change in line capacitance of the cable will de-tune the circuit, reducing the positive effect of the inductor.

This results in a ‘**double whammy**’ impact on the EPU load current.

- An increase due to increase in line capacitance.
- And, an increase due to the de-tuning of the inductor-capacitor resonant circuit.



THE ANSWER TO THE 'WHY' QUESTION



Two contributing factors that cause the fault-tolerance of the power distribution to be compromised:

1. The **effective capacitance** between the live conductors in the cable had changed.

2. The change in capacitance had **reduced the effectiveness of an inductor** installed at the EPU to provide Power Factor Correction (PFC).

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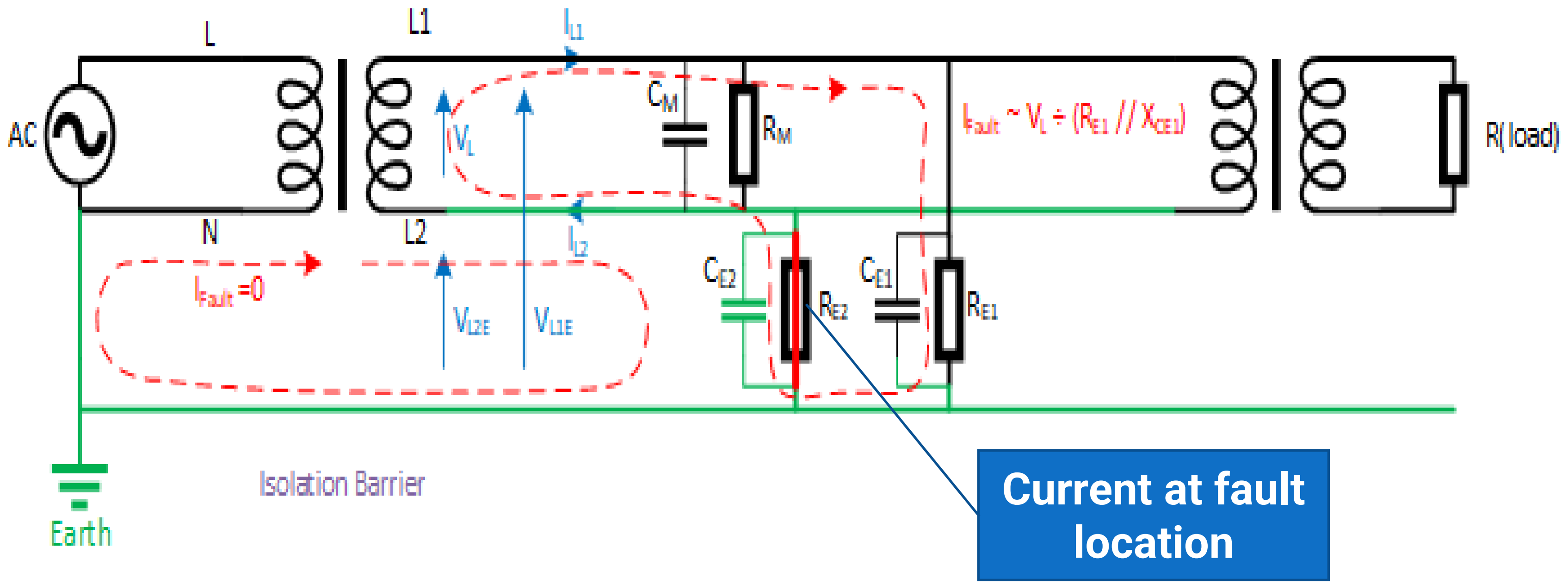
CURRENT AT THE FAULT

There will be a current through the fault, the magnitude of which is a function of the system voltage and the earth capacitance.

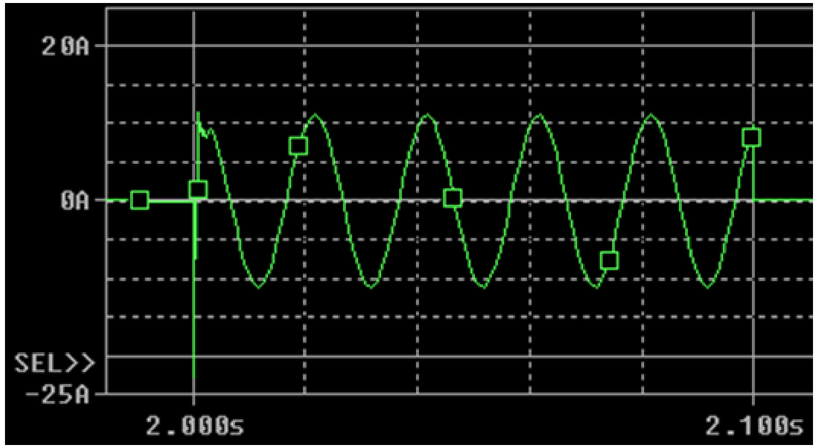


FAULT CURRENT

Detailed evaluation of the first fault condition using a modified distributed element transmission line model identified that potentially damaging currents are in fact likely to flow through any earth faults:

$$i_{FAULT} = 2\pi \cdot f \cdot C_{E1} \cdot V_{L1}$$

The current flowing through the fault will be approximately equal to the charging current of the cable in normal operating conditions.



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SUMMARY

- Umbilicals can have high capacitance and, if so, are not as fault tolerant as you might expect for an IT floating earth system.
- This only becomes a significant factor in systems that operate at higher voltages (~2.5kV and above) and/or with longer step out distances (~100km or greater). These generally go hand-in hand (i.e. higher voltages are generally required for longer step out distances).
- Power Factor Correction results in excessive EPU currents under earth fault conditions.
- Fault current through the short to earth will be approximately equal to the charging current of the cable in normal operating conditions
- Isolation of Subsea Power by over-current protection relays generally occurs after catastrophic damage at the earth fault.
- Maintaining a good Insulation Resistance in long umbilicals is critical to avoid rapid catastrophic damage.

RECOMMENDATIONS

- Acting on degrading Insulation Resistance early will prevent catastrophic consequences.
- Consequences of Power Factor Correction components under failure conditions should be fully analysed and understood.
- During FEEDs and detail design, System Electrical Analyses should consider failure modes not just normal operating conditions.

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Please contact us for more information on electrical integrity monitoring and insulation resistance improvement of subsea distribution systems.

Thank you

www.viperinnovations.com

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