Catastrophic Failures in Long umbIlicals

SUT Technical Meeting, 4th August 2020, Perth

THE QUEEN'S AWARDS FOR ENTERPRISE: INNOVATION 2016

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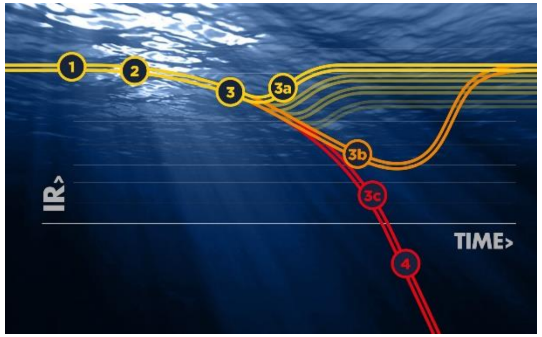

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Subsea Power Conditioning & Supply

V-SUPPLY®

Online Electrical Cable Integrity Monitoring & Fault Finding

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Integrity Management of Critical Subsea Assets

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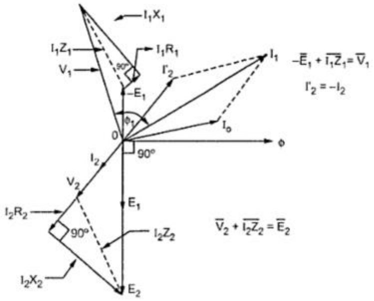
Power Distribution Systems

Three main considerations

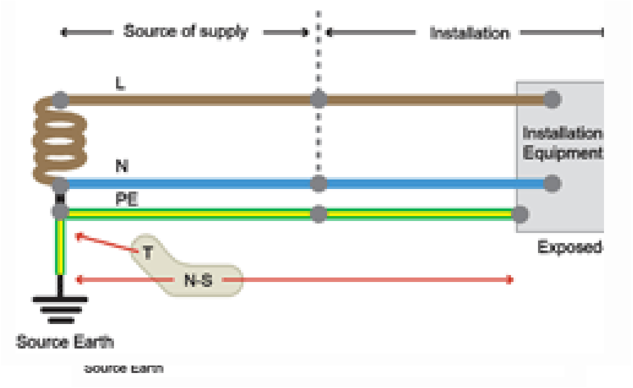


AC or DC | **Single or Multi Phase** | **Earthing**

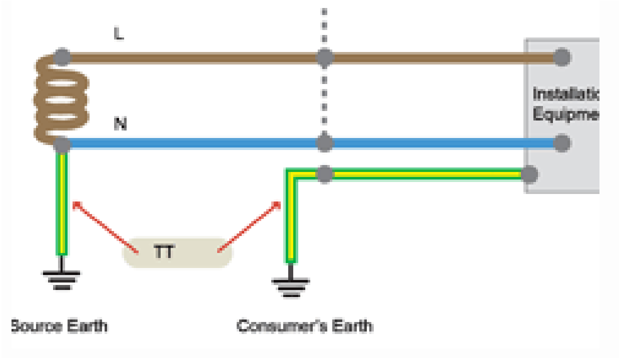
- Most subsea control systems utilise:
  Single phase, AC, ungrounded IT systems operating at <1000V
- Three phase systems have been used for long offset subsea controls
  Always ungrounded IT systems
- DC supplies are predominantly used in Subsea Controls by Schlumberger/OneSubsea

Earthing Arrangements

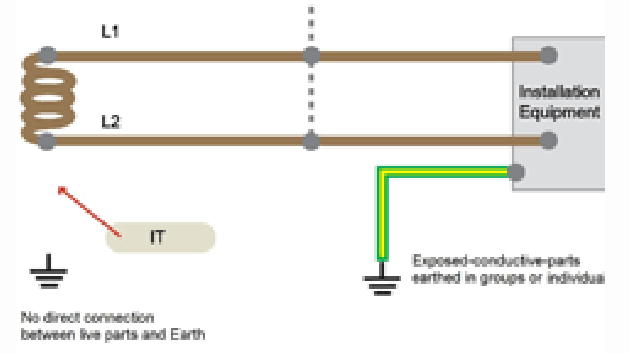
- IEC has standardised on three families of earthing – TN, TT, IT
- 1st Letter is connection between earth and supply
- 2nd Letter is connection between earth and device being supplied



TN



TT



IT

IT (Isolation Terra) Systems

- IT systems have no deliberate electrical connection to earth

- Continued supply on 1st ground fault
  - Could be down to Insulation resistance
  - Ground current on first fault is very small
  - Effectively grounds one side to turn IT system into a TT system

- **If a 2nd ground fault occurs**
  - Can lead to dangerous body currents lacking protection
  - Other phase(s) rise to phase-to-phase voltage – impressed on conductor. Increases electrical stress.

- 1st fault must be fixed ASAP

CASE STUDY – A CONFLICT WITH THEORY?

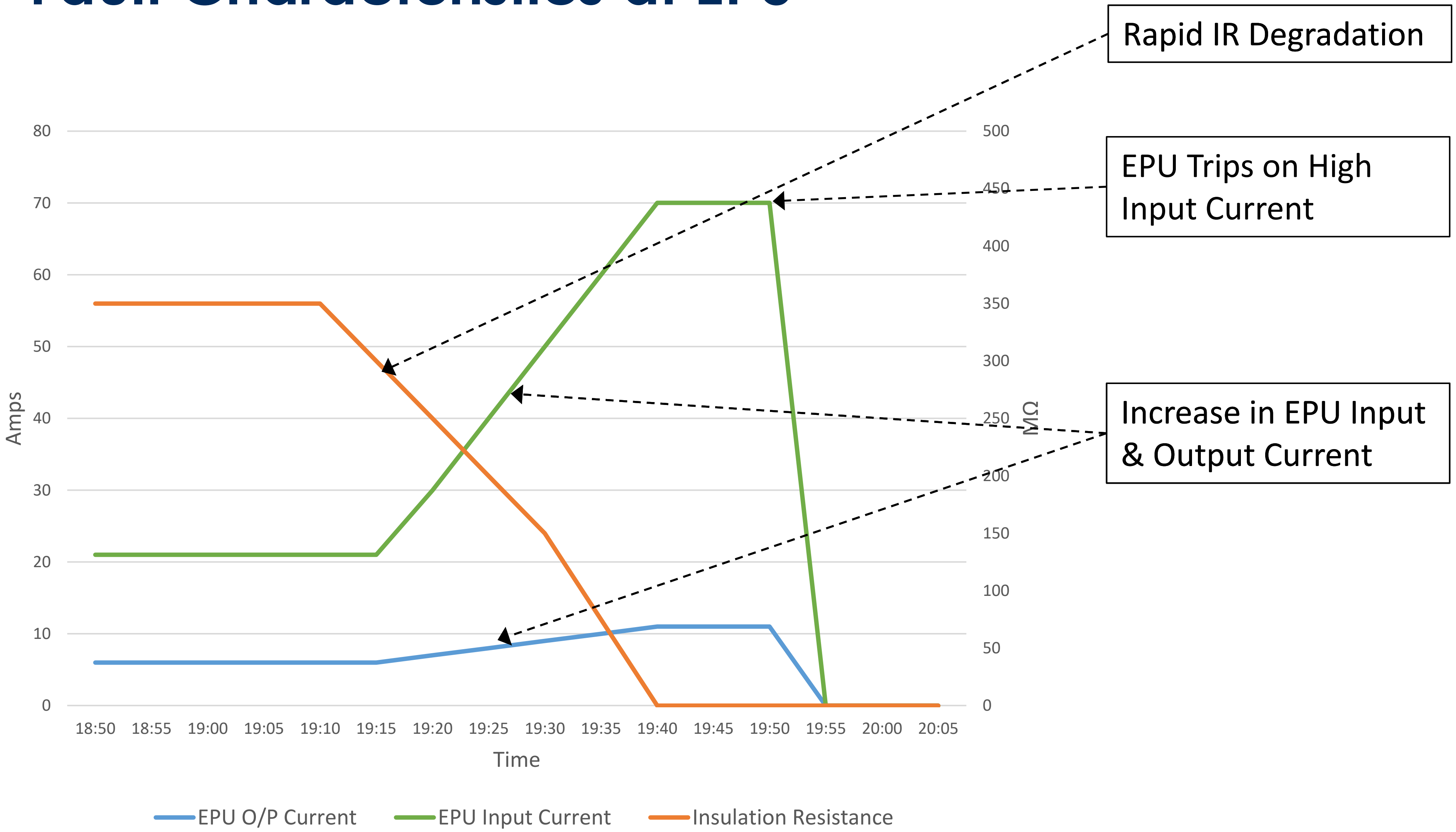
The Facts

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/termination.
3. The umbilical was long (>100km)

Why?

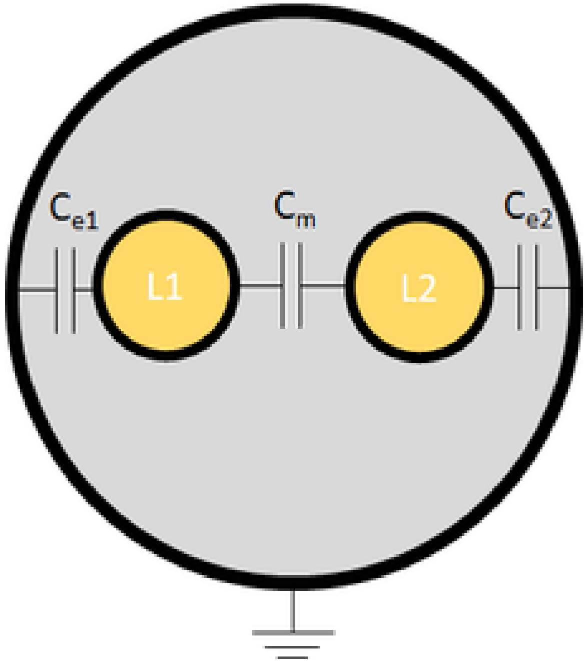
What caused the over-current?

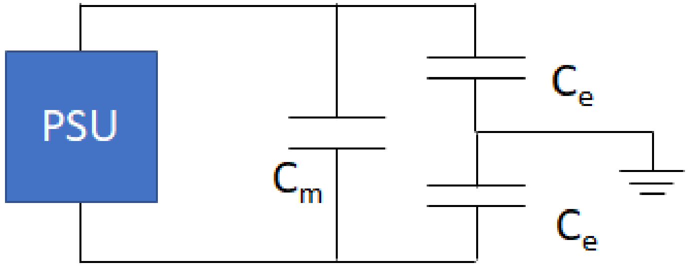
Fault Characteristics at EPU



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





$$C = C_m + C_e/2$$

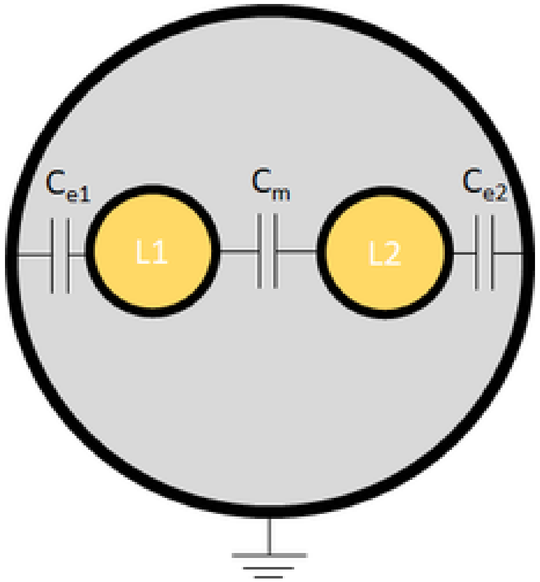
For a general twin core cable the earth capacitance (C_e) is approximately twice that of the mutual capacitance between the conductors (C_m), therefore;
$C_e = 2 \times C_m$ or $C_m = C_e/2$

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 result in an increase in the specified Capacitance per unit length

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

AC TRANSMISSION & CAPACITANCE

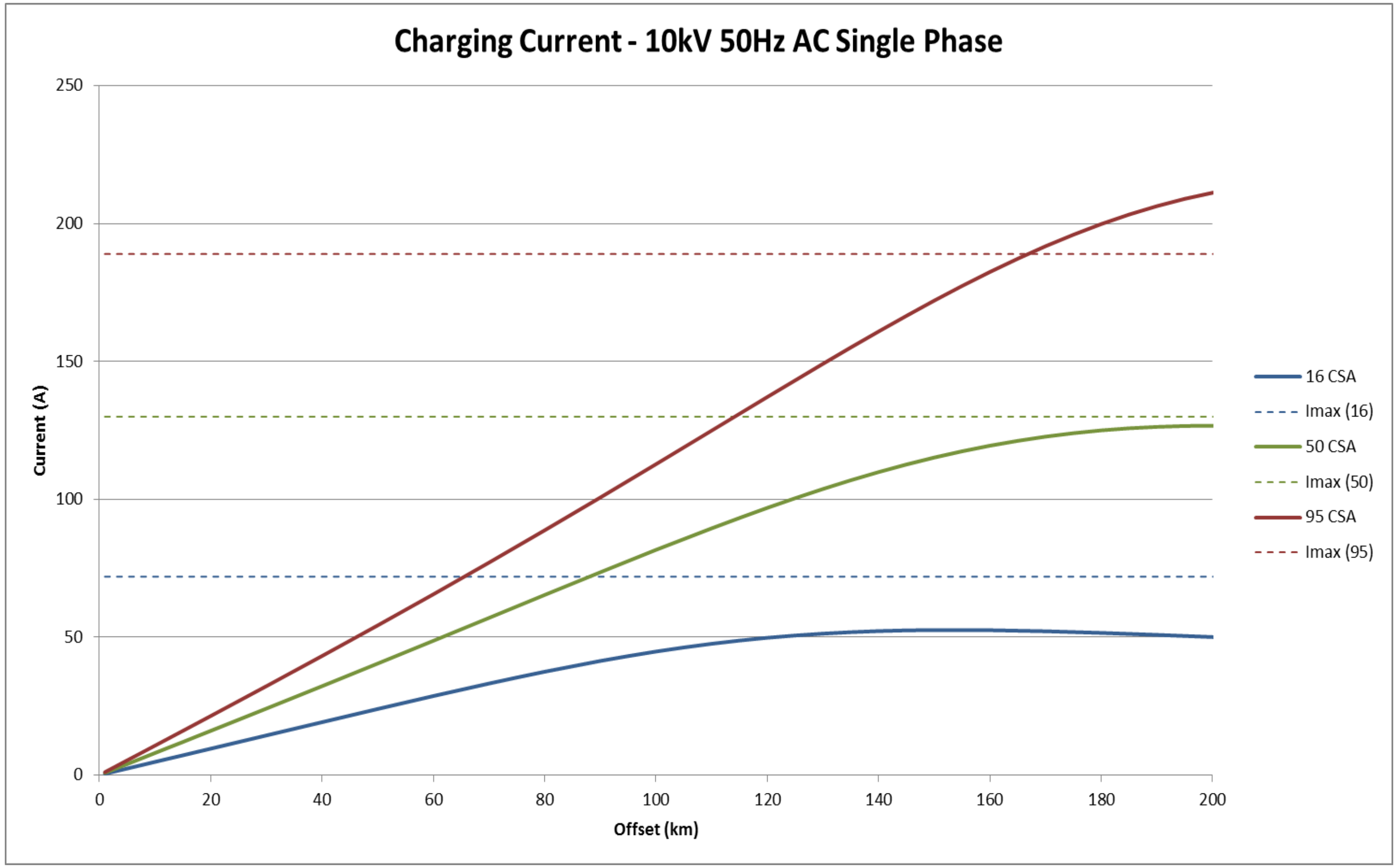
In submarine systems where cable capacitance is high, it dominates the transmission characteristics

Cable manufacturers usually specify the cable capacitance per unit length (for long cables, this is usually in nF/km). Therefore, it can be noted that the charging current for a given cable 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.

AC TRANSMISSION

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.



POWER FACTOR CORRECTION

In order to reduce the impact of the cable charging current on the power supply, 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 addition of the inductor, which is tuned to the cable capacitance at the line voltage operating frequency (usually 50 or 60Hz), creates a resonant circuit. This reduces the magnitude of the Reactive Power (VAr) drawn from the PSU, improving the phase angle between the Complex Power (VA) and the Active (or Real) Power (W), thereby reducing the load capability requirements of the power supply.

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.

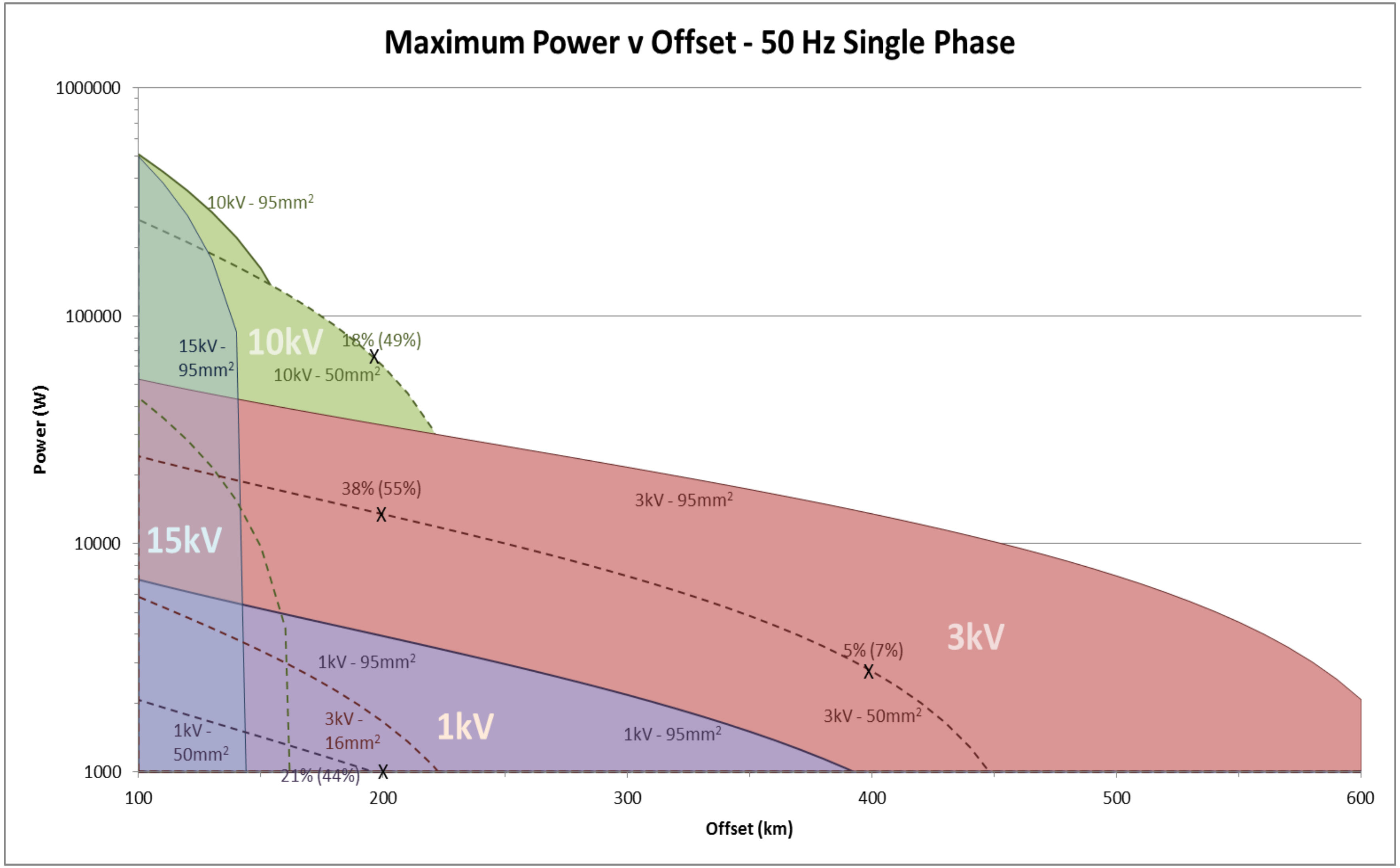
MORE URBAN MYTHS

- Traditional / common assumptions for power delivery:

    - Increase in voltage will increase offset capability
    - Increase in CSA will increase offset capability
    - Increase in voltage will improve efficiency
    - Increase in CSA will improve efficiency

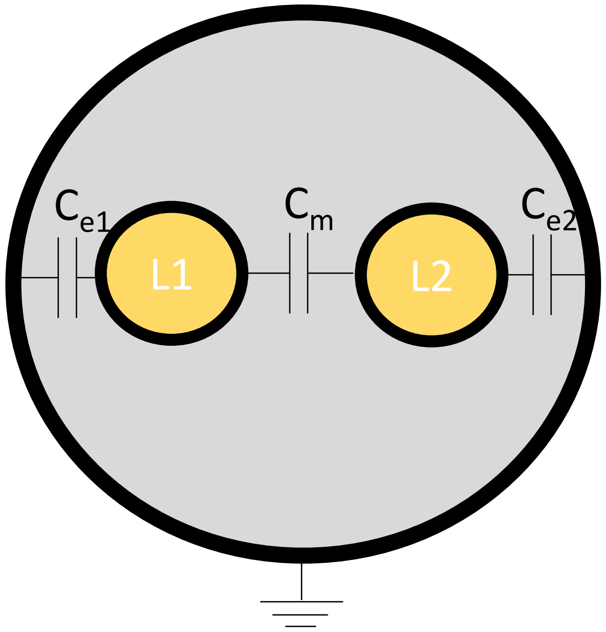
- Definitely true for DC systems but AC systems are far more complex

POWER VS OFFSET (SINGLE PHASE)



Single Earth Fault

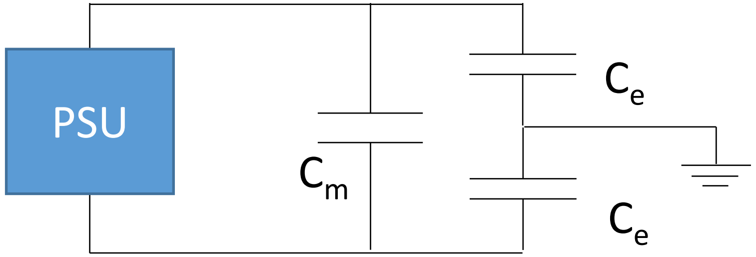
If series resistance, inductance and resistive leakages are not significant



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

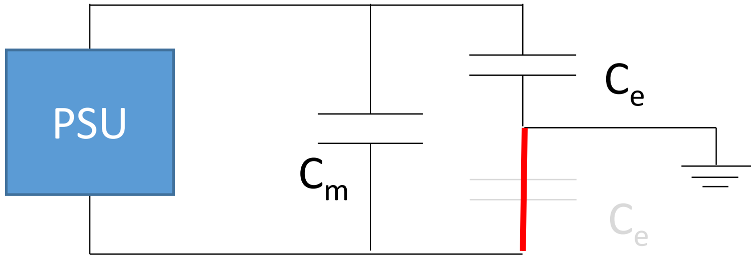
Under Normal Operation

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



Single Earth Fault

Total Capacitance
$= C_m + C_e$



Consequences;

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

AC TRANSMISSION

The approximate line capacitance during first fault conditions is 50% greater than during normal operating conditions.

More Advanced Cable Modelling shows the increase to be 35-40%

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 PSU load current.

Increase due to increase in line capacitance.

Increase due to the de-tuning of the LC resonant circuit.

THE ANSWER TO THE 'WHY' QUESTION

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 connection/termination.
3. The umbilical was long (>100km)

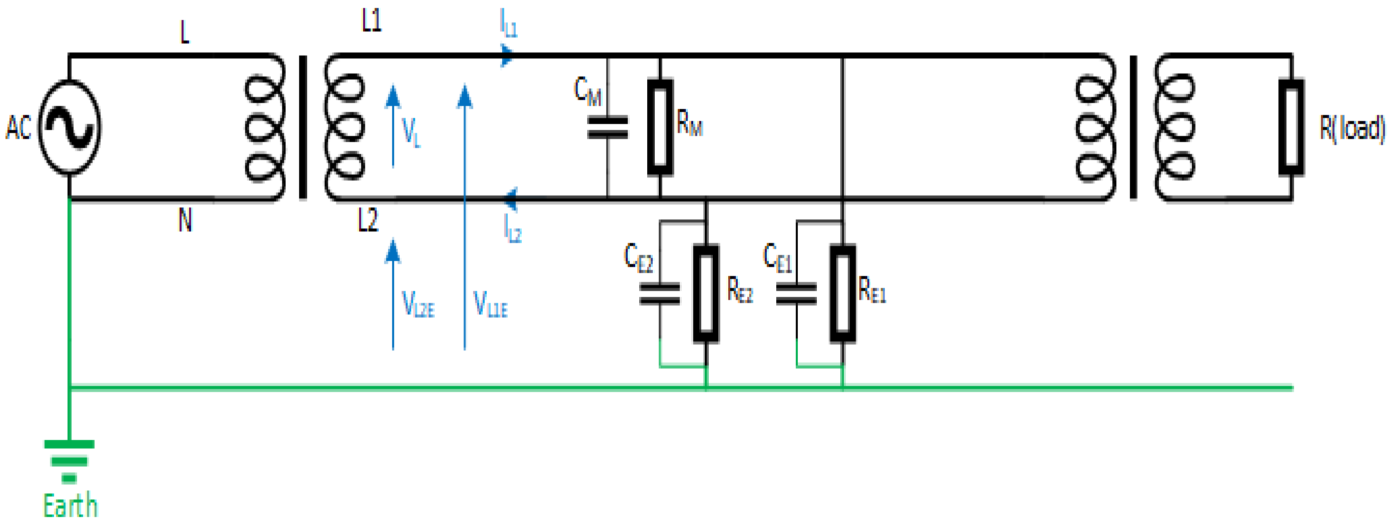
Why?

What caused the over-current?

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

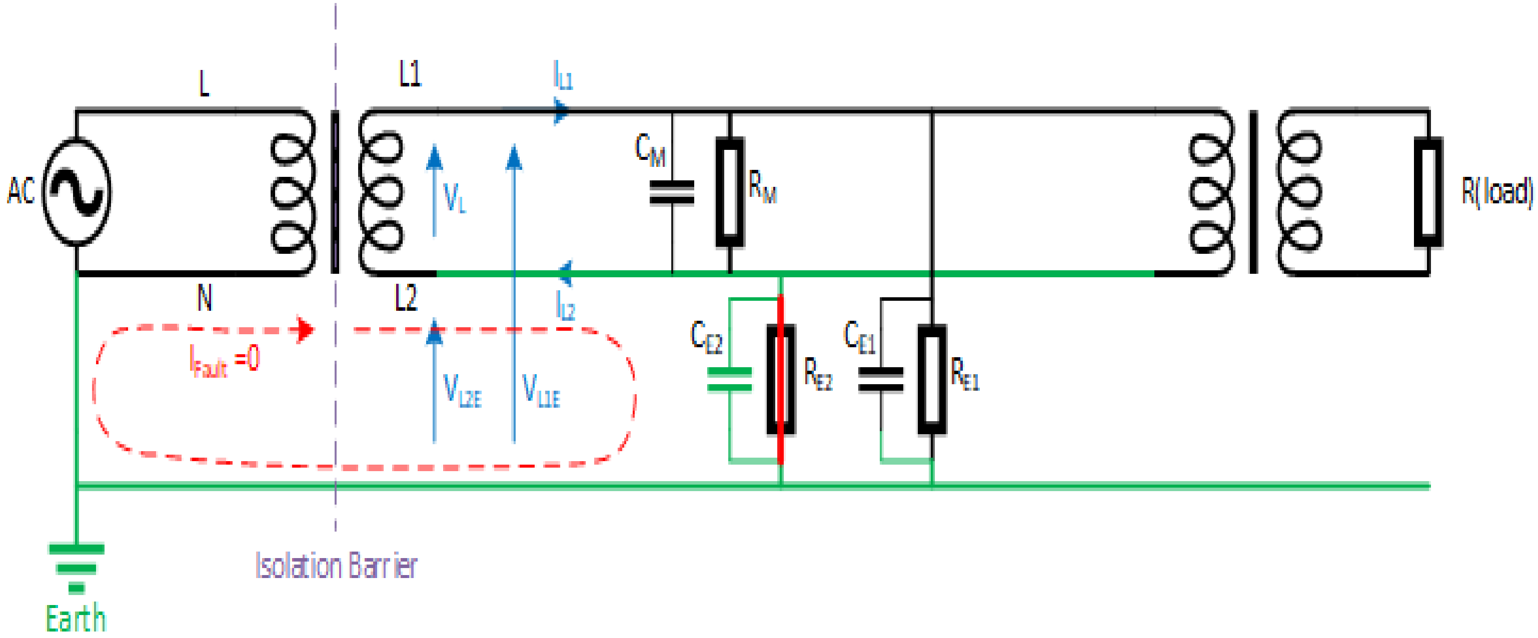
1. The effective capacitance between the live conductors (L1 & L2) had changed.
2. The change in capacitance had reduced the effectiveness of an inductor installed in the EPU to provide Power Factor Correction (PFC)

NORMAL OPERATION



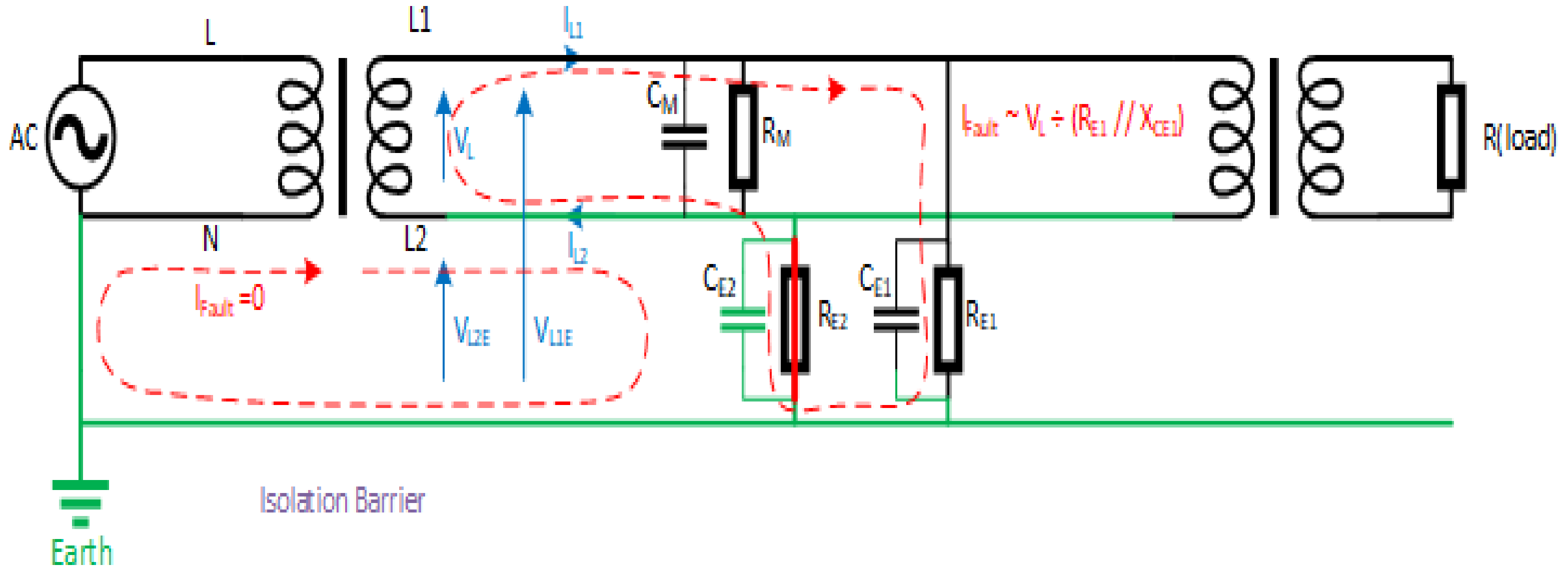
CURRENT AT THE FAULT

If the entire L2 conductor is now at earth potential (V_{L2E} = 0). If both sides for the fault are at the same potential there cannot be a current flow?



CURRENT AT THE FAULT

There will, in fact, be a current through the fault, the magnitude of which is a function of the Voltage on the non-faulted conductor (in this case V_{L1E}) and the leakage impedance ($R_{E1} + X_{CE1}$)

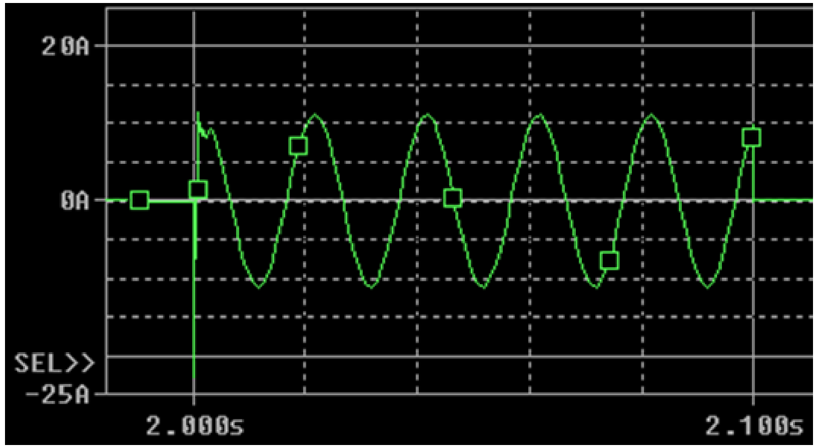


FAULT CURRENT

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:

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

Recalling that the line to earth capacitance for a single conductor (C_e) is approximately equal to the stated total line capacitance (C), it becomes apparent that the current flowing through the fault will be approximately equal to the charging current of the cable in normal operating conditions.



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.
- For three-phase, long offset systems, a numerical distance protection relay should be used.
- 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.

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

Thank you

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