# REMOTE POWERING
# TEST RESULTS & MODELING

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# AGENDA

1. Test Setup
2. Comparison of Test Methods
3. Result – Bundle Size vs. Heating
4. Result – Current vs. Heating
5. Result – DC Loop Resistance vs. Heating
6. Conclusion
7. References
8. Annex

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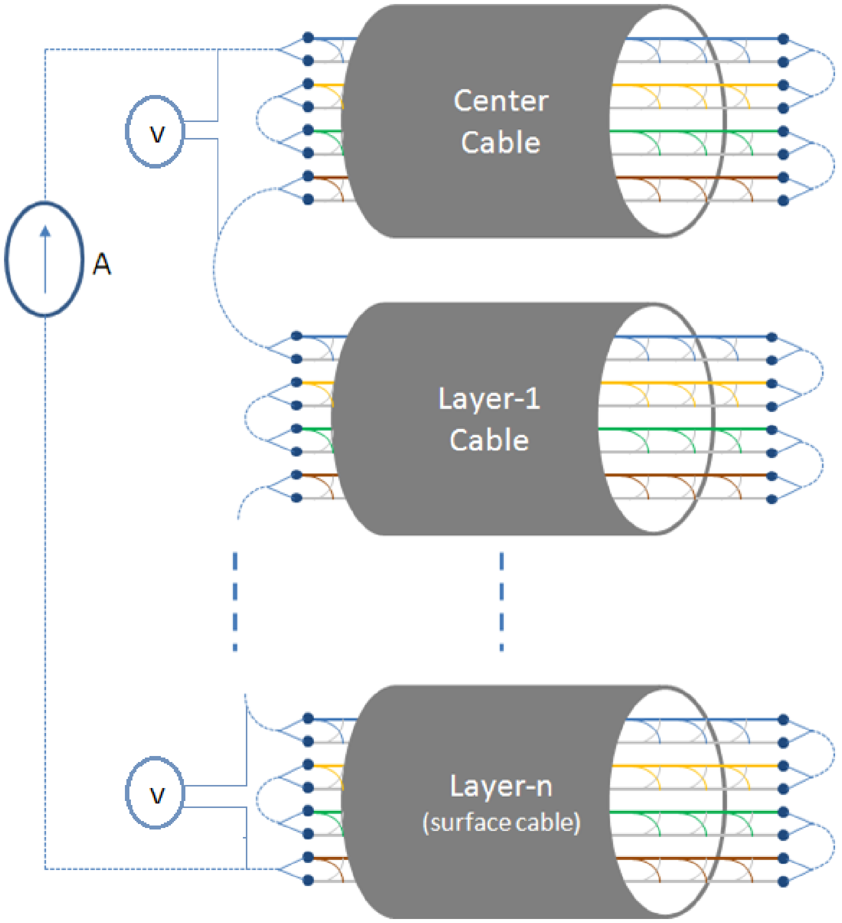
# 1.1 Bundling Methods

**Standard IEC PAS 61156-1-4**

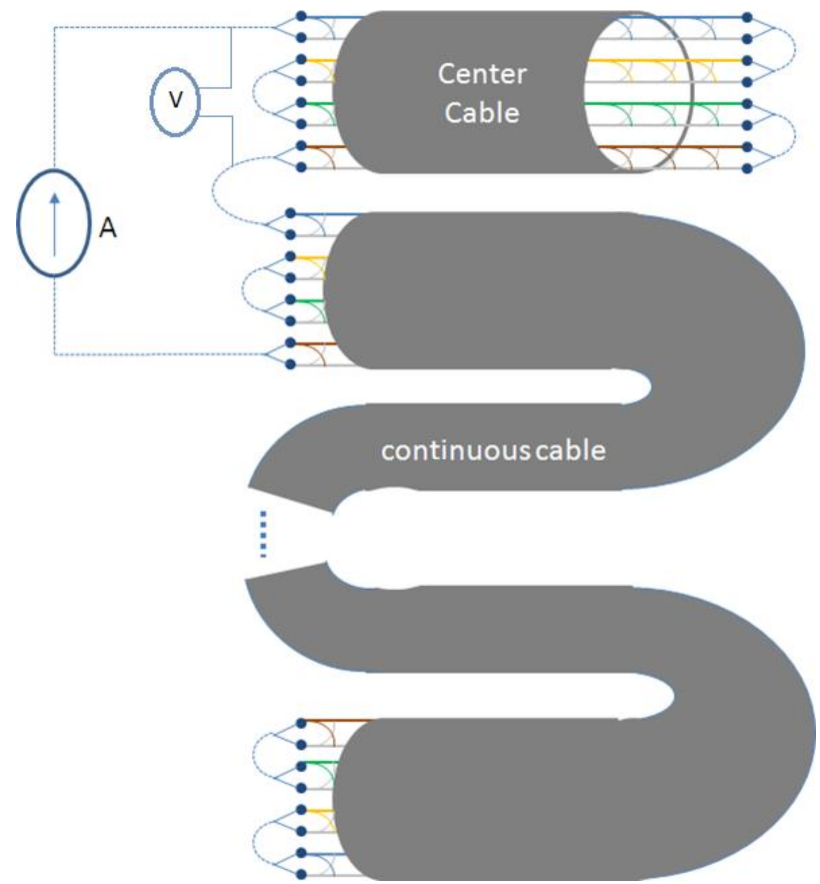
- Separate cables are connected in series
- Pairs are in series to each other



# 1.1 Bundling Methods

**IEC Proposal Document – 46C/934e/NP**

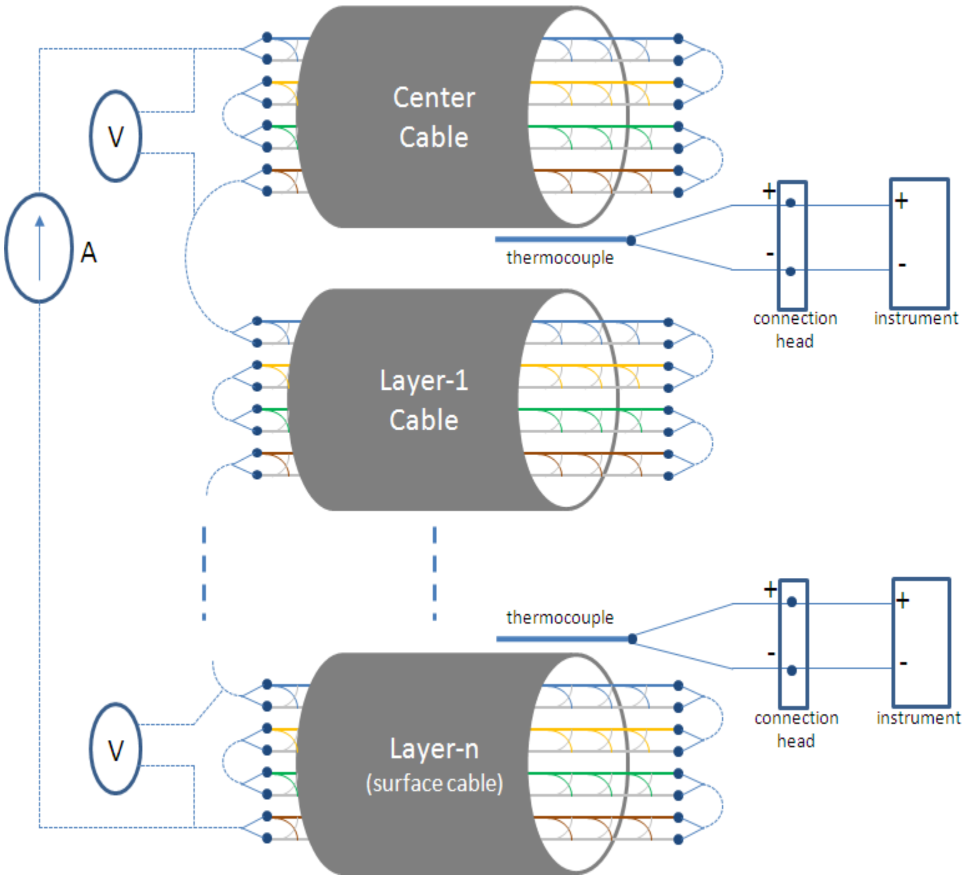
- NP proposed by UK in 2010/11 – not sufficient support
- Separate cable in the center *optionally added for DC-resistance measurement*
- Same continuous cable for all layers
- Pairs are in series to each other
- Similar to CLC but with additional access to center cable
- Possible amendment for IEC



# 1.2 Measurement Methods

Bundling acc. Standard IEC PAS 61156-1-4 ($l$ > 3m)

- 350mA and 600mA are applied applied per pair standardized
- 800 mA and 1 A are provided
- Resistance Calculation
  - Voltage difference between centre cable end-connections
- Additional resistance calculation available for each layer (e.g. layer n)
- Possible Amendmet: Thermocoupler
  - On the center cable
  - Between layers
  - Ambient Temp.



## 1.2 Measurement Methods

- Resistance Calculation: **Standard IEC PAS 61156-1-4**

$$T_i = T_{initial} + \left(\frac{R_i}{R_{initial}} - 1\right)\frac{1}{K}$$

$$\Delta T_{(i-initial)} = \left(\frac{R_i}{R_{initial}} - 1\right)\frac{1}{K}$$

$$K = 0.00393$$

# 1.2 Measurement Methods

Thermocouple Measurement

- ***Pros***: Absolute value, easy to mount on a bundle
- ***Cons***: Outer cable jacket temperature instead of conductor temperature, lower resolution

Resistance Calculation

- ***Pros***: Conductor temperature, higher resolution
- ***Cons***: Relative to initial resistance ($R_{initial}$), hard to measure $R_{initial}$ without high current, stable connections to voltmeter needed

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# 2. Comparison of Standardization Documents*

| | Test Environment |
|---|---|
| **draft EN50174-99-1** | • Different test conditions: free air, wire basket, tray, within insulation material |
| **IEC 46C-934e-NP** | • A stable environment free of drafts and significant thermal fluctuations shall be used. It can be by a structure made from fibre board, consisting of a double walled design, with radiation shielding for the heating means.<br>• No account is taken of external thermal insulating factors; no EMC<br>• The enclosure shall be heated to the maximum ambient specified for the intended application<br>• Amdt. for different test conditions (cp. EN 50174-99-1) |
| **IEC PAS 61156-1-4** | • Free space not to restrict heat convection and there should be no additional draft<br>• Room temperature<br>• 4-6 hours for thermal equilibrium |

***see Annex for detailed comparison**

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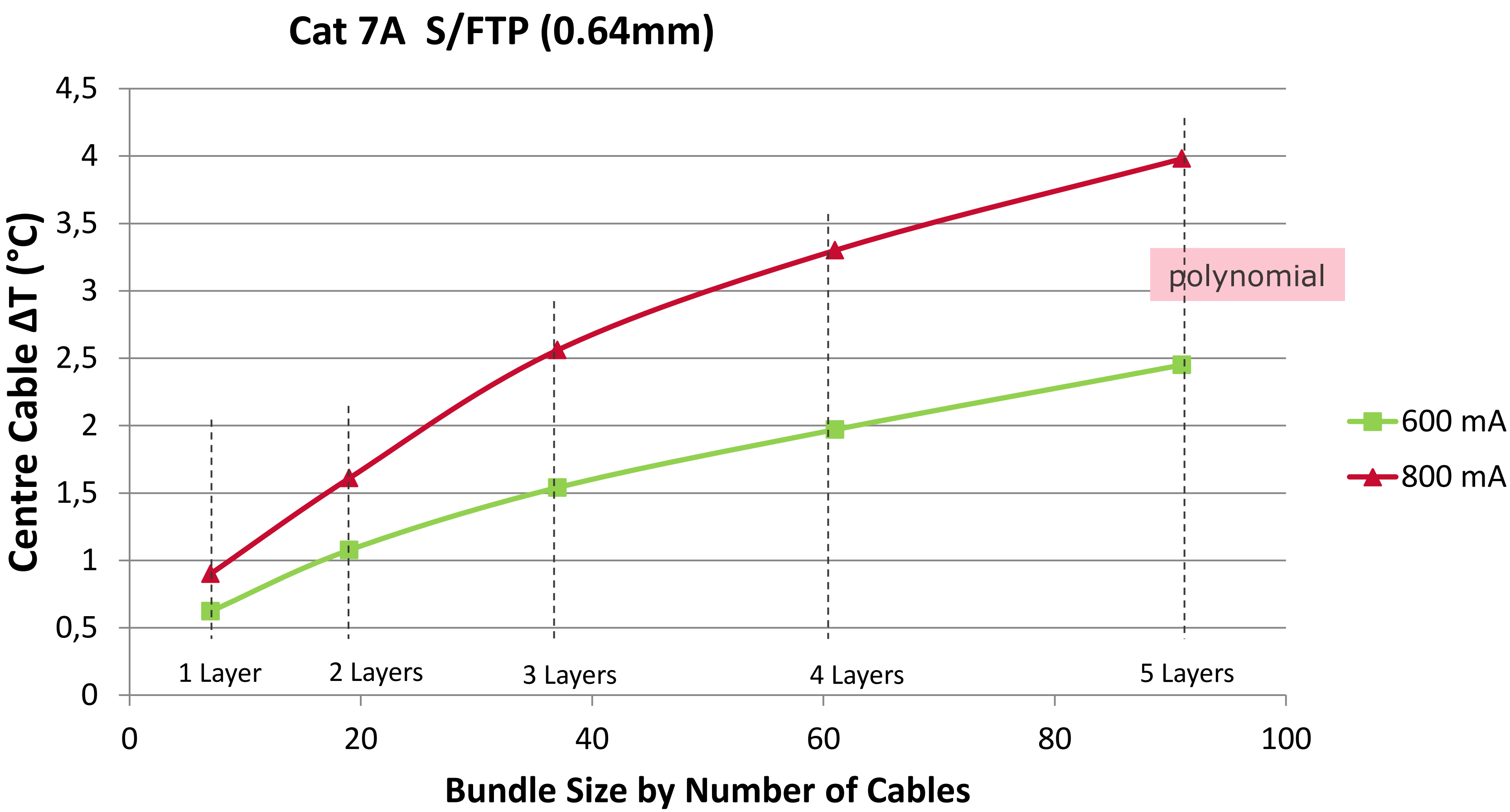
# 3.1 Measurement Results

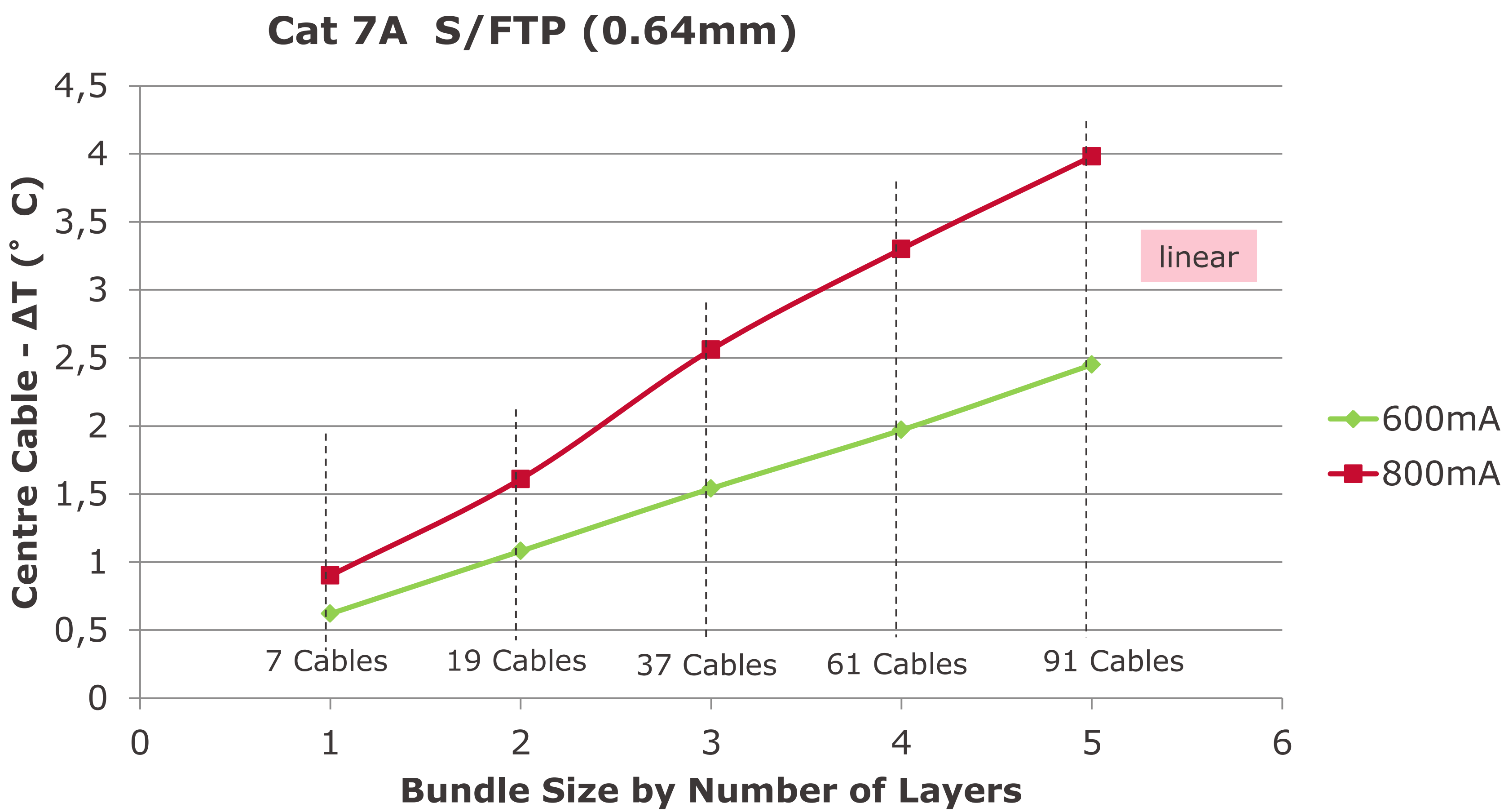
Center cable heating of different sized-bundles of
**the same cable and the constant current**




*Dots indicate test results

# 3.1 Measurement Results

Center cable heating of different sized-bundles of
**the same cable and the constant current**




***Dots indicate test results**

# 3.2 Modeling

Cable number vs. Heating

(same cable and constant current)

$N_{cable}$: total number of cables

$N_{layer}$: total layer of bundle

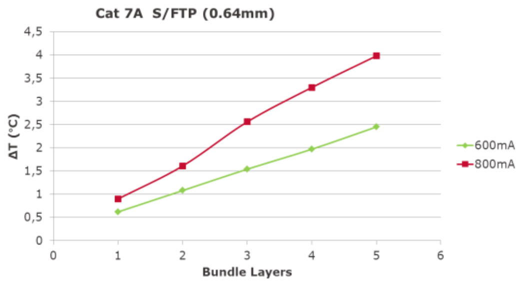
m,n: coeff. for linear equation

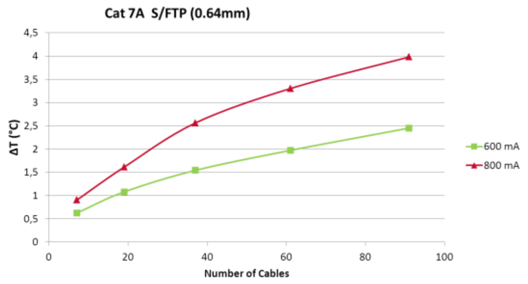
$$N_{cable} = 3N_{layer}^2 + 3N_{layer} + 1$$

$$\Delta T = mN_{layer} + n$$

$$\Delta T = m\left[\frac{-3+\sqrt{12N_{cable}-3}}{6}\right] + n$$

For 100 cables → $\Delta T = m5.266 + n$



# 3.2 Modeling

- In addition to Cat 7A S/FTP nominal 0,64 mm conductor diameter (AWG 22) cable,
  - Cat 6A U/FTP nominal 0,56 mm (23AWG),
  - Cat 7 cables for work area wiring S/FTP nominal 0,42 mm (26AWG) are tested to create the model
  - Cat 5e U/UTP 0,50 mm (AWG 25).

- From the model, *m* & *n* coefficients are needed to be solved for each cable and at each current level.
- 2 measurement samples are needed at the same current level but different bundle levels to derive *m* & *n*
  - E.g. for Cat.7A and 800 mA *m*=0,7567 and *n*=0,0966 in slide 13

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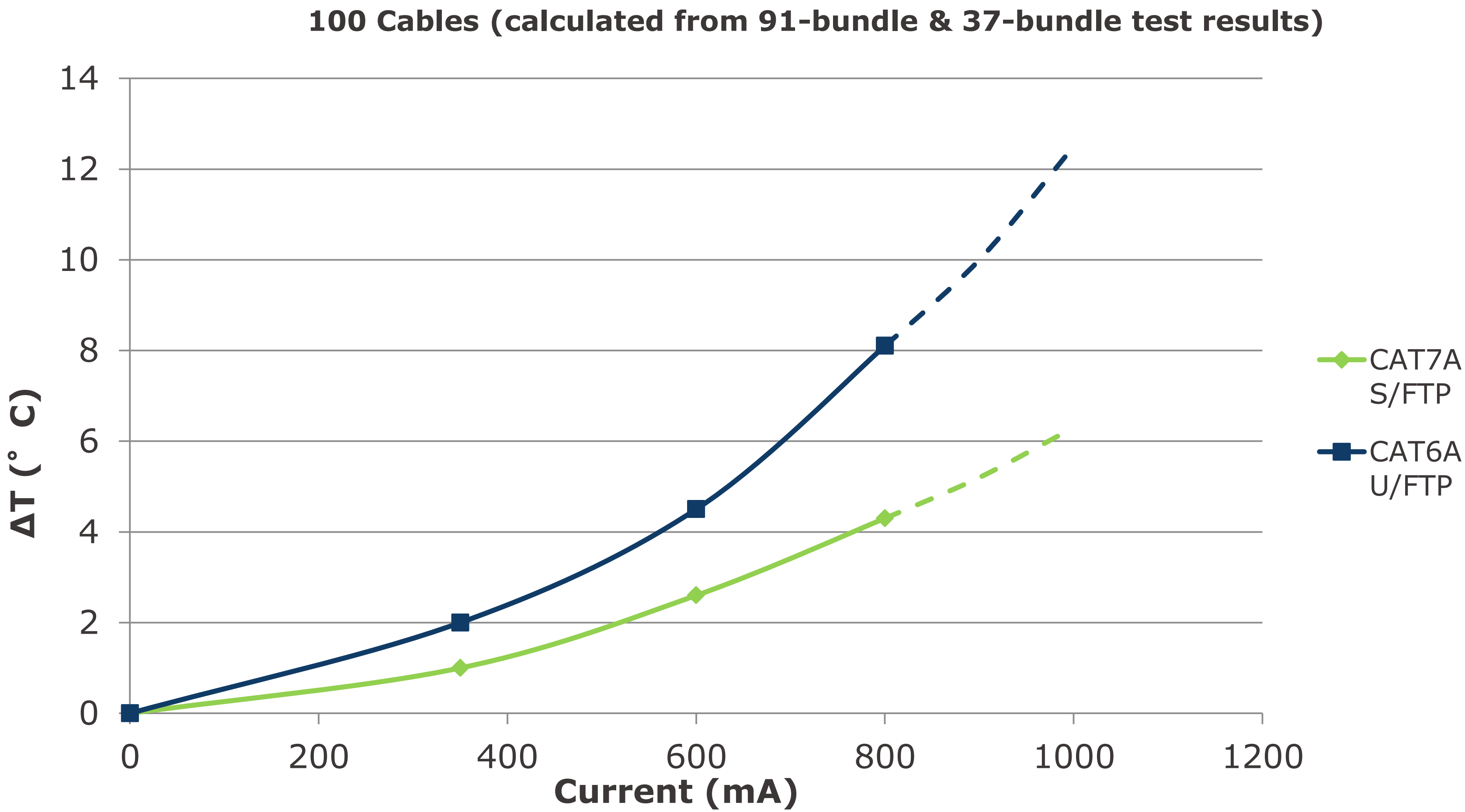
# 4.1 Results




**Dots indicate 100-cables calculation from test results, dashed line is the approximation for higher currents (see next slide)**

# 4.2 Modeling

P: power

ρ, k: coeff.

I: applied current

R: cable resistance

Current vs. Heating

$$\Delta T \propto P$$

$$\Delta T(I) \propto I^2 R(T)$$

Differential equation $\longrightarrow$ $$\Delta T(I) = \rho I^2 R(T)$$

Simplified by constant R $\longrightarrow$ $$\Delta T(I) = k I^2 R_{initial}$$

This approximation gives higher errors at higher current levels

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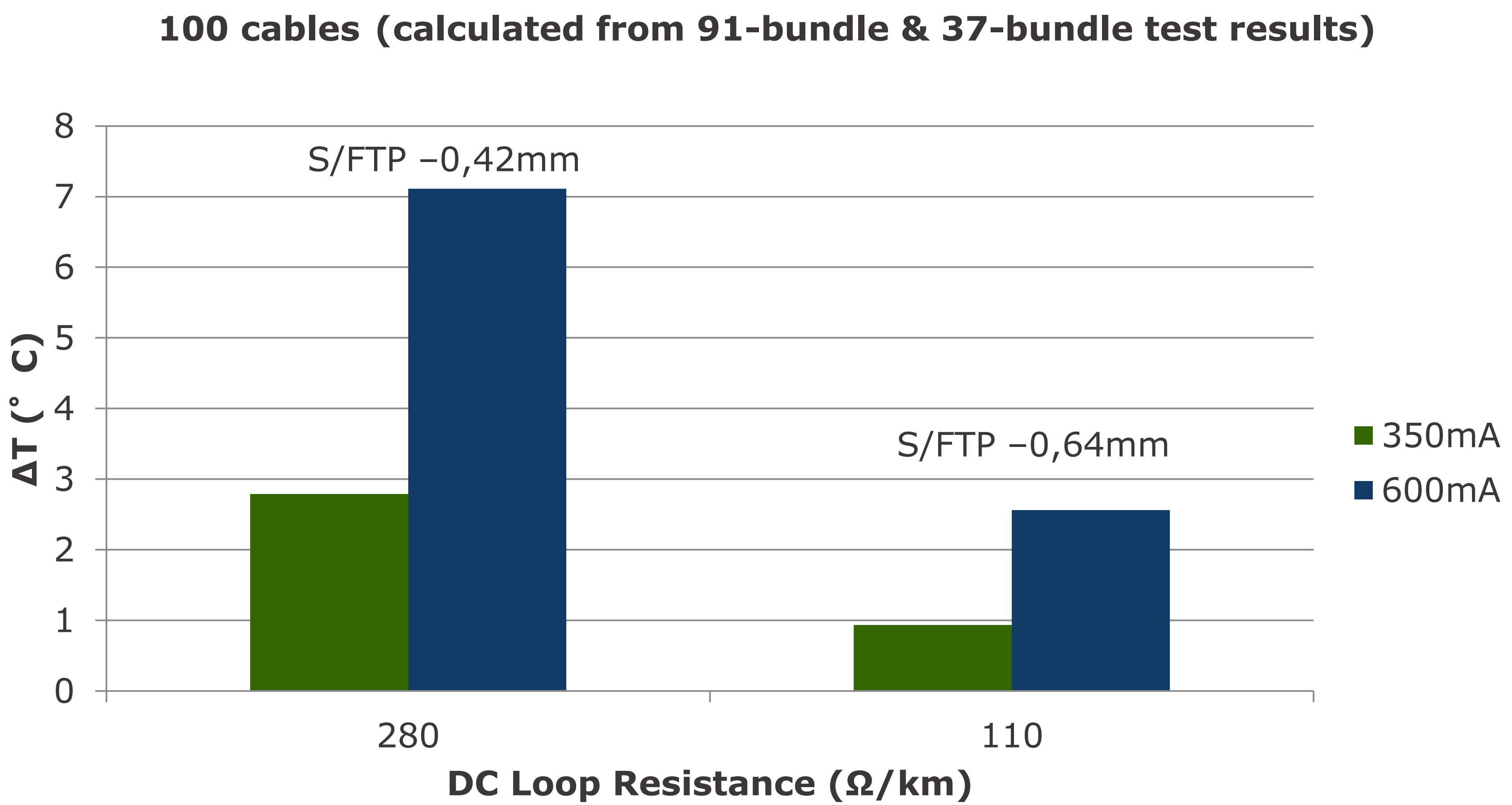
# 5.1 Results


100 cables (calculated from 91-bundle & 37-bundle test results)
S/FTP –0,42mm
S/FTP –0,64mm
ΔT (° C)
0
1
2
3
4
5
6
7
8
280
110
DC Loop Resistance (Ω/km)
350mA
600mA

# 5.2 Modeling

DC Loop Resistance vs. Heating

$$\Delta T_1 = k_1 I^2 R_{DC\ Loop_1}$$

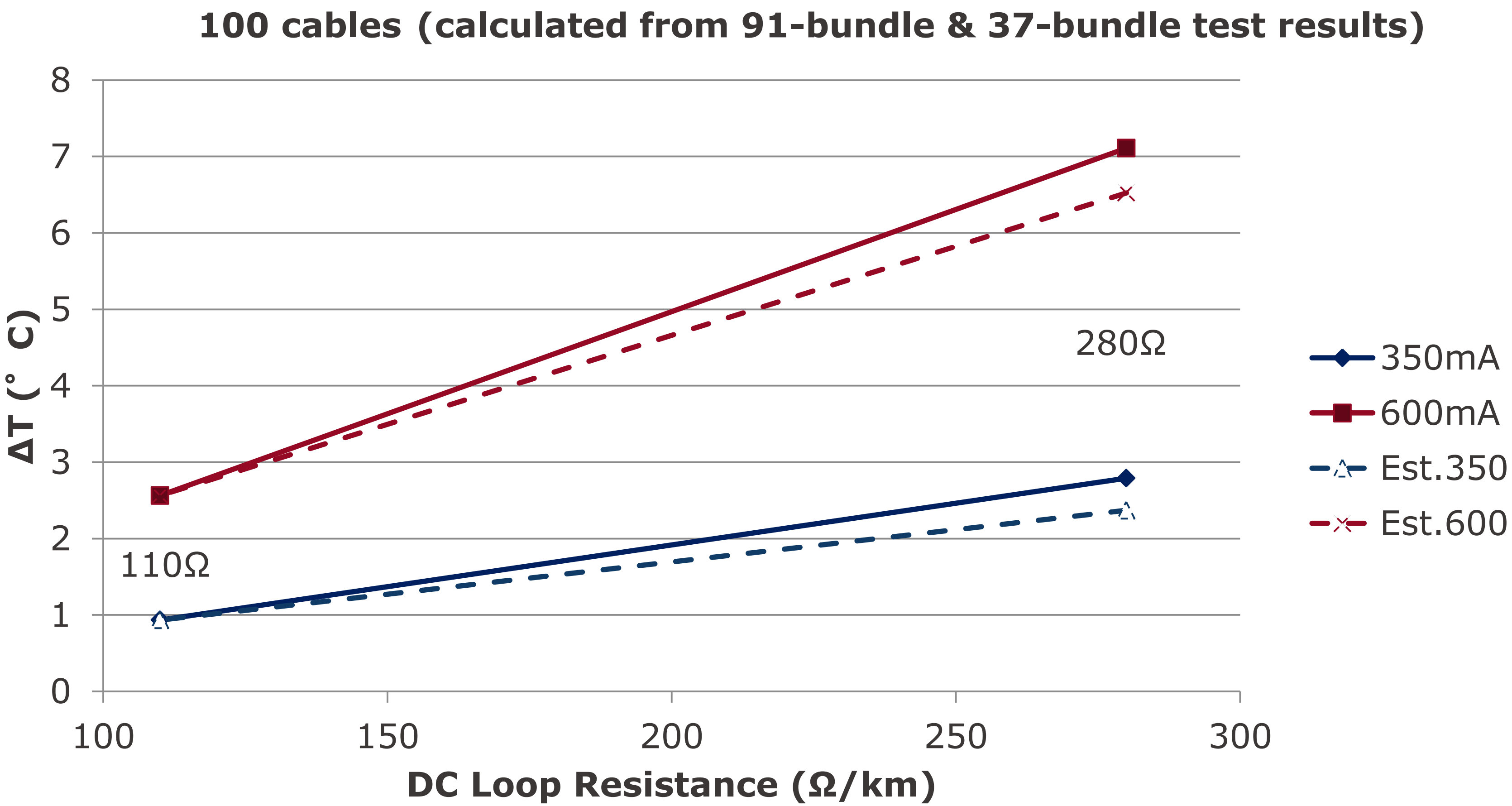
$$\frac{\Delta T_1}{\Delta T_2} = \frac{k_1 R_{DC\ Loop_1}}{k_2 R_{DC\ Loop_2}}$$

If both have the same designs,
$k_1 \approx k_2$

$$\frac{\Delta T_1}{\Delta T_2} \approx \frac{R_{DC\ Loop_1}}{R_{DC\ Loop_2}}$$

Linear approximation, only if the same designs

# 5.3 Modeling – Estimation




***Dots indicate test results, dashed line is the calculated approximation**

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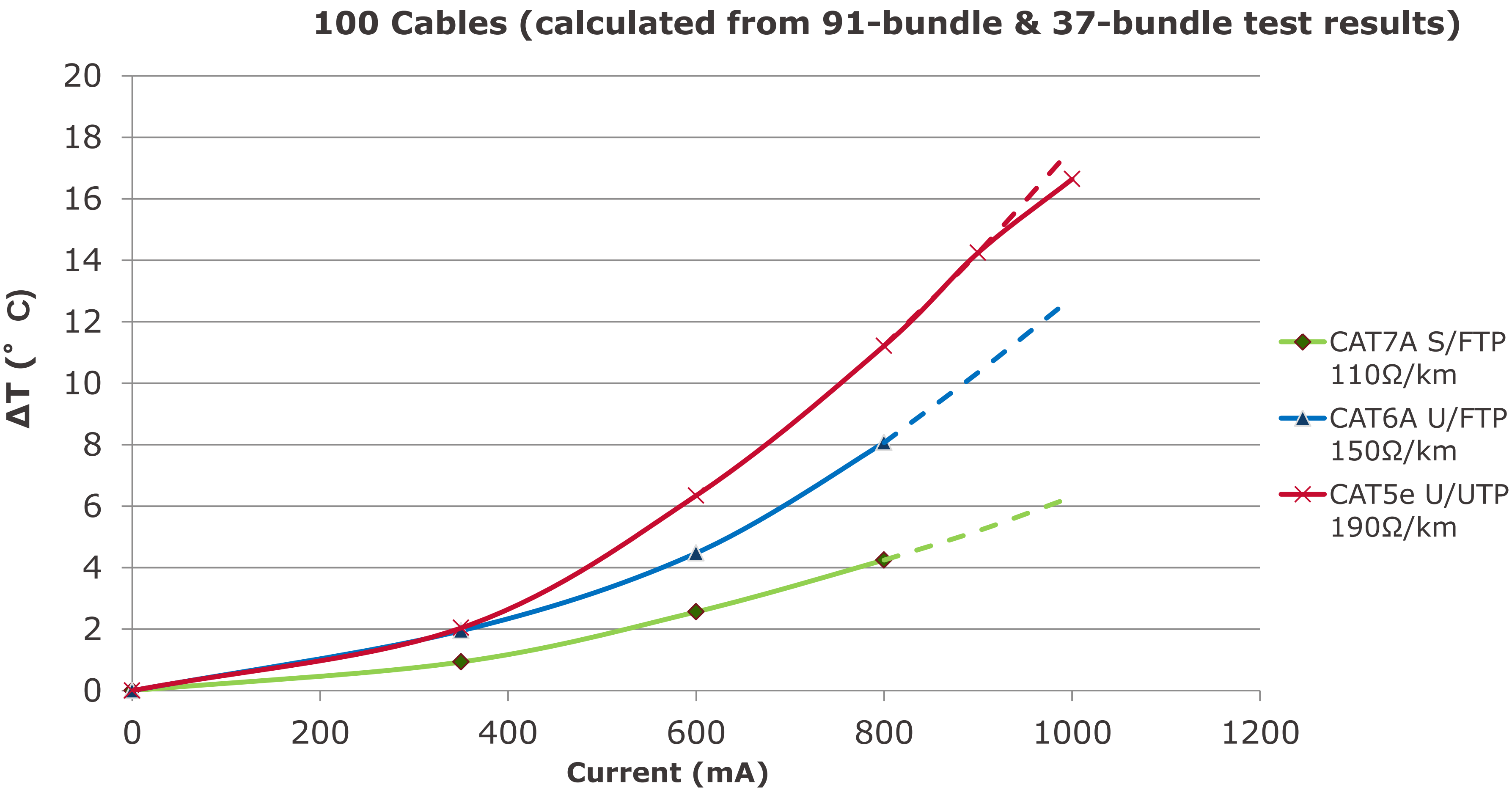
# 6.1 Conclusion – Estimation




***Dots indicate test results, dashed line is the calculated approximation**

# 6.2 Conclusion

- Testing Methods are needed to be clarified in terms of testing environment, measuring methods

- **Model.1 - Bundle size vs. Heating**: It is possible to calculate heating for desired cable number by using 2 test (1 test sample also possible but with low error rate).
  - There is linearity only between bundle layer number & heating
- **Model.2 – Current vs. Heating**: Heating for different current levels is calculated by approximation with error level.
  - Exponential relationship
- **Model.3 – DC Loop Resistance vs. Heating**: By avoiding all cable design factors, heating is directly proportional to DC Loop Resistance. However cable design affects the proportion rate.
  - IEC is working on committee draft TR 61156-1-6 on DC resistance for different categories (see liaison IEC SC 46C)

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# References

- **PoE Test Method EN50174-99:**
„TESTING PROTOCOL FOR THE PRODUCTION OF TEMPERATURE RISE DATA IN SUPPORT OF CLC TR 50174-99-1"
http://www.fia-online.co.uk/pdf/L6164_clcwg2-33-04_test_protocol.pdf

- **IEC 46C-934e-NP**
IEC/TS 61156-1-x Ed. 1.0: Multicore and symmetrical pair/quad cables for digital communication – Part 1-x: Measuring the temperature behavior of cables in bundles when fed with DC

- **IEC/PAS 61156-1-4 Ed. 1.0**
Multicore and symmetrical pair/quad cables for digital communications - Part 1-4: Symmetrical pair/quad cables with transmission characteristics up to 1 000 MHz - Conductor heating of bundled data grade cables for limited power transmission based on IEEE 802.3

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# ANNEX

| | Bundle | Test Set-up |
|---|---|---|
| **PoE Test Method EN50174-99** | • Min. 3 Layers-37 cables;<br>• Min. length is 2.4 m<br>• Continuous cable bundling | • Min 6 thermocouples (4 is vertically on layers, 2 for the sides at a distance of 0.6 ± 0.05 m from the middle;<br>• Series wire connection |
| **IEC 46C-934e-NP** | • Not less than 7, but 19 & 37 cables can be tested;<br>• Min. length is 30D (50D is recommended), as D being bundle diameter<br>• Continuous cable bundling | • More than 6 thermocouples (2 for vertical, 4 is in axial);<br>• Bundle is mounted in horizontal;<br>• Series wire connection |
| **IEC PAS 61156-1-4** | • Length is 3-5 m<br>• 91 to 127 cable bundles are indicated<br>• Separate cables are bundled with lay-plates, interconnections inside layers are made and lay-plates are removed. Then, interconnections between layers are made so that all wires are in series. The ends of the bundle have to be covered with thermal insulating foam. Small pieces of a polymeric tube should be used to protect the access of the end of the cables used for the measurements. Foam spray shall be 2-3 cm at least | • Measuring resistance of a conductor. Take initial resistance at room temp and measure resistance change while heating up. It is more real conductor temp instead of measuring conductor surface by probes.<br>• Bundle is suspended by 1m distance to the ground and walls, 2m to the ceiling and in horizontal manner.<br>• Circuit connection installation with 2-pair test and 4-pair test options |

# ANNEX

| | Test Environment | Test Equipment Accuracy |
|---|---|---|
| **PoE Test Method EN50174-99** | • Caution to be aware of different conditions: free air, wire basket, tray, within insulation material | • The current stability shall be within 10mA (ffs).<br>• Thermocouples shall have an accuracy of ± 1 ºC<br>• Thermocouple Ta may be a more appropriate ambient temperature meter (or built into a mass which limits sensitivity of the thermocouple to air movement). |
| **IEC 46C-934e-NP** | • A stable environment free of drafts and significant thermal fluctuations shall be used. It can be by a structure made from fibre board, consisting of a double walled design, with radiation shielding for the heating means.<br>• No account is taken of external thermal insulating factors; no EMC<br>• The enclosure shall be heated to the maximum ambient specified for the intended application | • In order to minimize their influence on measurements; thermocouples shall have as small an outside diameter as practicable. It is recommended that they are not more than one tenth of the outside diameter of the smallest cable in the bundle. |
| **IEC PAS 61156-1-4** | • Free space not to restrict heat convection and there should be no additional draft<br>• Room temperature<br>• 4-6 hours for thermal equilibrium | • No specification<br>• Precision resistance instrument is needed for conductor resistance measurement prior to powering<br>• Constant current source |

# ANNEX

| | Test Procedure | Applied Current (per pair) |
|---|---|---|
| **PoE Test Method EN50174-99** | • No explanation | 2-pair powered<br>• 350mA for PoE Type-1<br>• 600mA for PoE Type-2<br>4-pair powered<br>• 248mA for PoE Type-1<br>• 424mA for PoE Type-2<br>• 600mA for UPOE (4-pair PoE+, Cisco)<br>• 900mA for HDBASE-T<br>• 1800mA for industry maximum |
| **IEC 46C-934e-NP** | • All horizontal thermocouples are within 3°C at heated ambient temp<br>• Sample measurement is taken every 15 min.<br>• Saturation is when 3 consecutive results are within 2°C, or after 24 hours (3 readings within 4°C). | • No specification |
| **IEC PAS 61156-1-4** | • Voltage across the conductor is measured to calculate the resistance, and hence temperature<br>• It is important to measure the resistance initially at room temperature<br>• Thermal equilibrium is reached after 4-6 hours for 97-127 cables | • 350mA for POE<br>• 600mA for POEP |

# Thank you.