

Small components. Big impact.

Cabling of PV installations – Key factors for a successful long-time reliability



YOUR BANKABLE PARTNER

STÄUBLI

Stäubli Group – three activities, four divisions



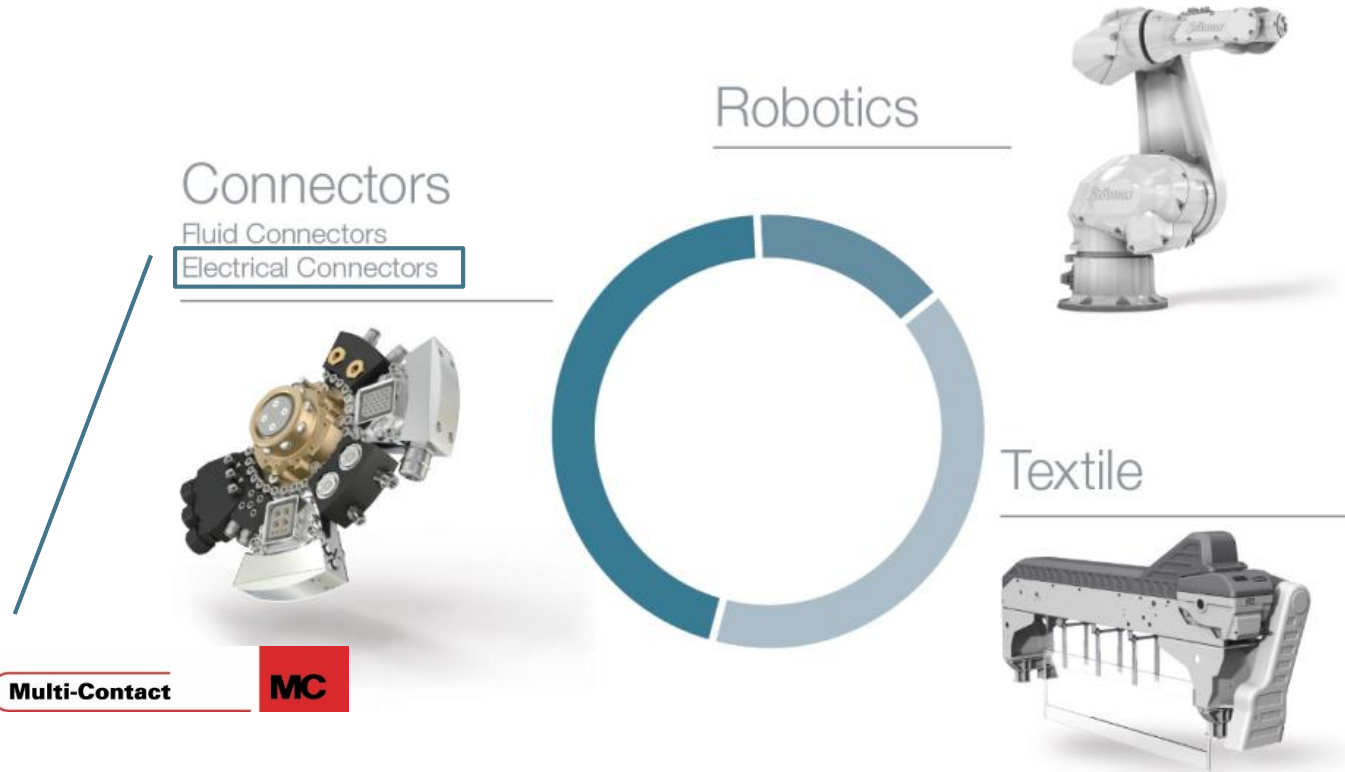
> 125 years experience



> 5500 employees in 29 countries

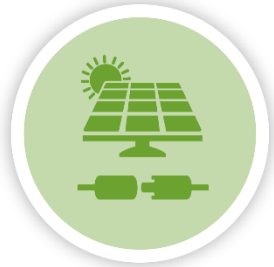


> 400 GW PV connected

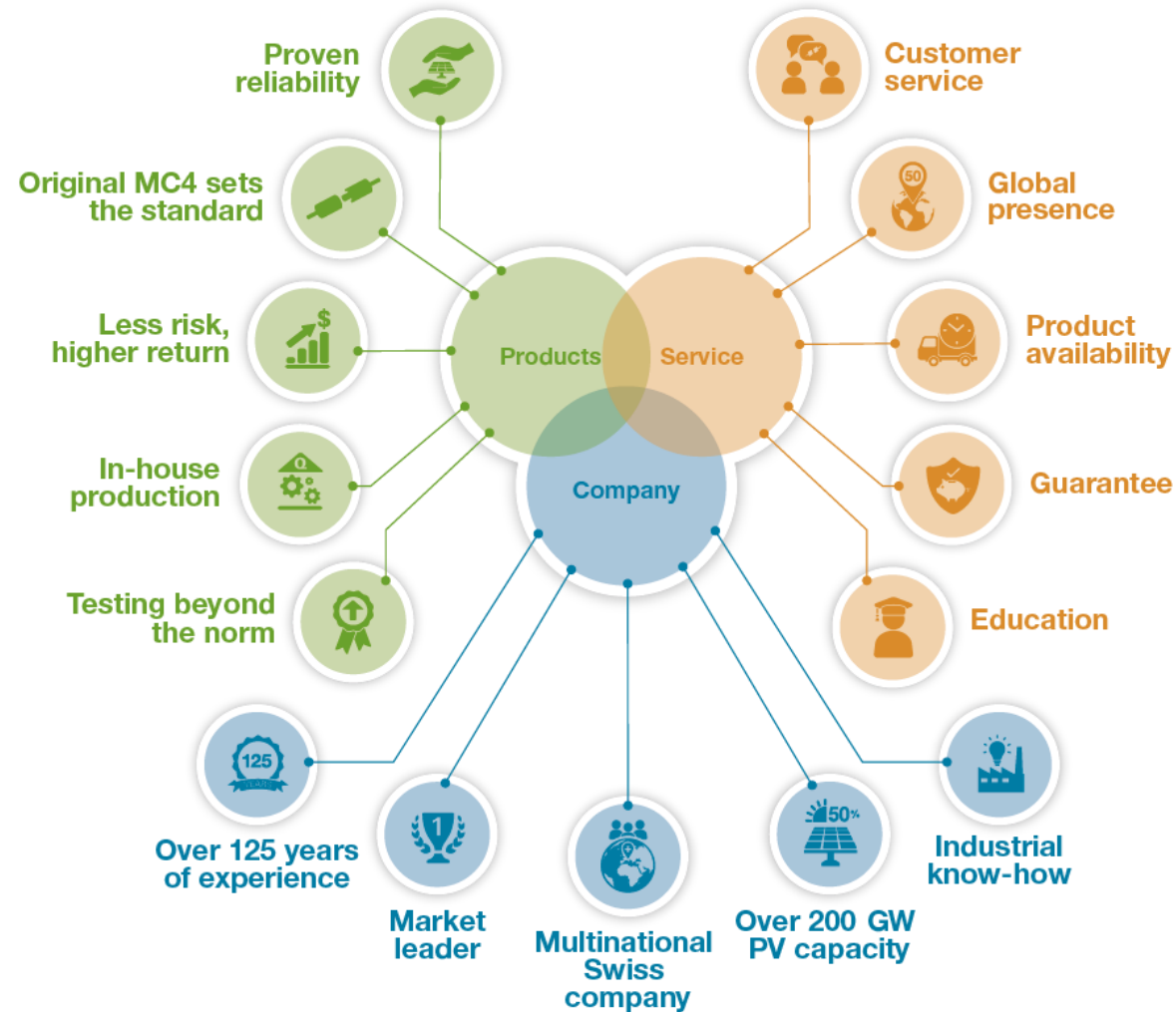


Your bankable partner – More than “just” a product

Products



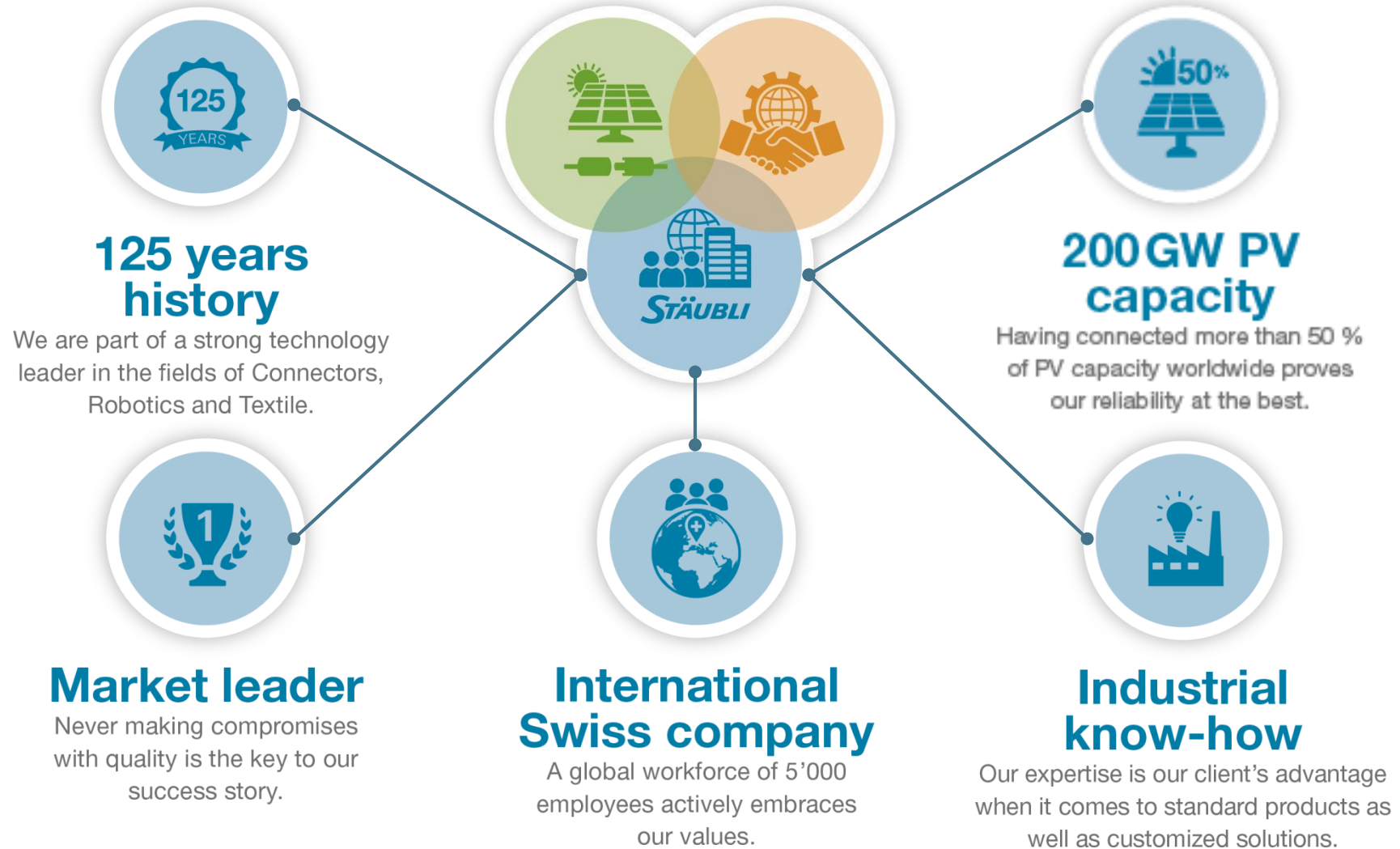
Company



Service



Our attention to detail builds trust. And trust builds best results.



We don't just make quality. We live it.



We stand by your side as your partner – in every part of the world.



Cabling of PV systems – You can't manage the unknown

Lack of knowledge about eBoS components (cabling/ connectors) ...

- Component → technology, norms, materials, production processes
- Installation → norms, tools, assembly instructions

... and their relevance for the long-term success of a PV system

- Technical issues and their root cause
- Consequences/ risk on safety, efficiency (LCOE), profitability (ROI)

Resulting in eBoS components failures

Higher costs and losses



(Credit: Walmart lawsuit)

Failures and their financial impact

Solar Bankability project by European Commission's Horizon 2020

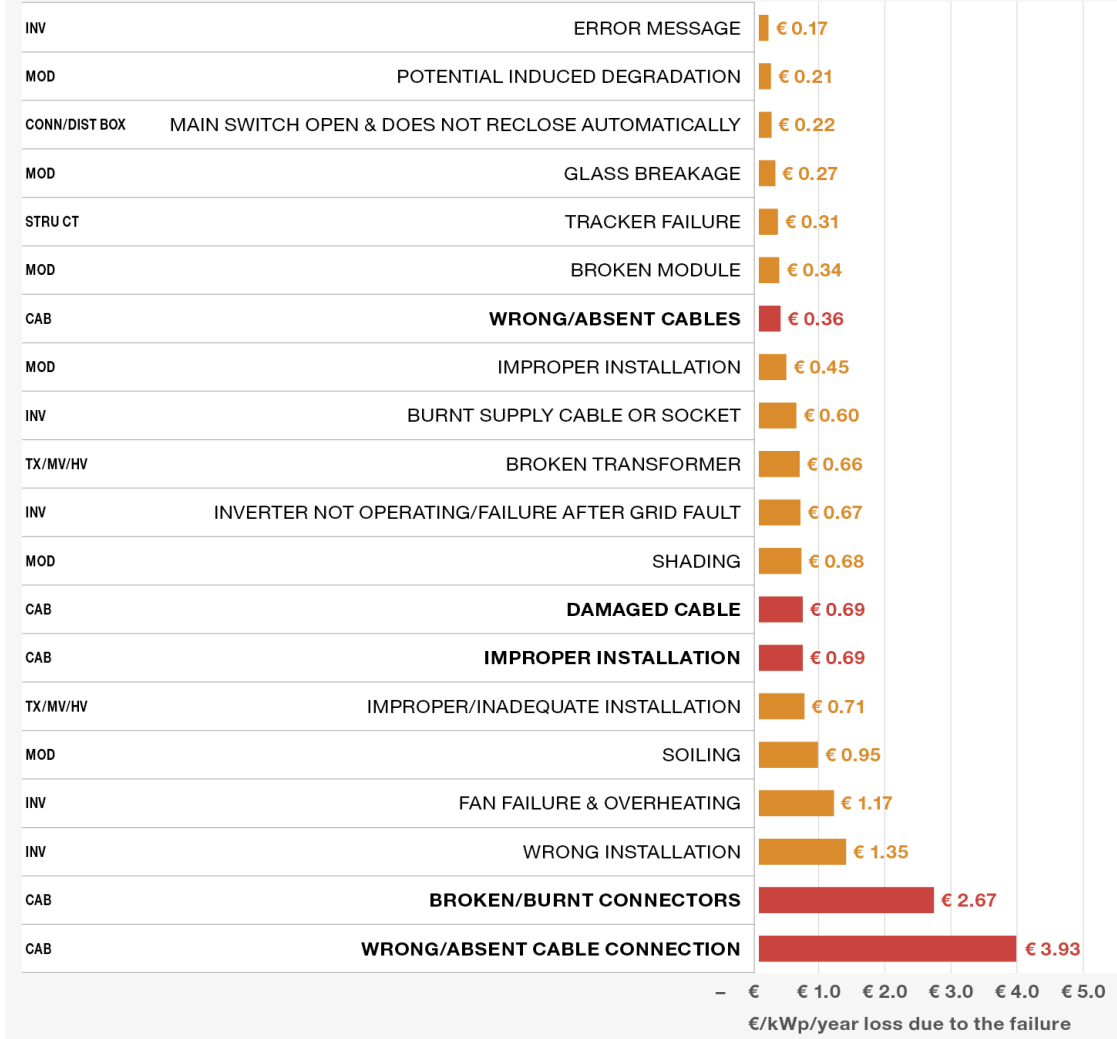
Common practice for professional risk assessment to reduce risks for investments in PV projects

- CPN (cost priority number) = cost-based failure mode and effects analysis (FMEA)
- Method was applied to database of >1 million documented failure claims (empirical and statistical)
- Technical failures/risks and their economic impact due downtime and/or power loss & repair/substitution costs
- Indication of the economic risk (in average) of a specific technical risk

**Cable & connector with huge financial impact
→ Euro/ kWp/ year loss due to the failure**

Risk mitigation measures with objective to minimize the LCOE by optimizing the balance between CAPEX & OPEX

Top 20 technical failures



Failures in PV systems – You can't manage the unknown



(Credit: Walmart lawsuit)

After reviewing the damage caused by fires, Walmart said in some instances it appeared Tesla personnel made cable connections using connectors that were not compatible.

Walmart said its investigations "quickly discovered that Tesla routinely deployed individuals to inspect the solar systems who lacked basic solar training and knowledge."

Failures in PV systems – You can't manage the unknown

4.1.2 Field assembled connectors and string cables

The Sunbolts-compatible connectors of the string (homerun) cables were often found to be assembled in an inappropriate manner:



Fig. 4-7: string connector on negative pole of string 0105-14

The cable gland nuts of many connectors were found damaged, obviously because pliers were used for tightening, rather than the appropriate wrench tool with torque control (Mfgr. P/N: 112G0-003344-R1). The nuts were often seen skew on their threads leading to irregular compression of the inner gasket.

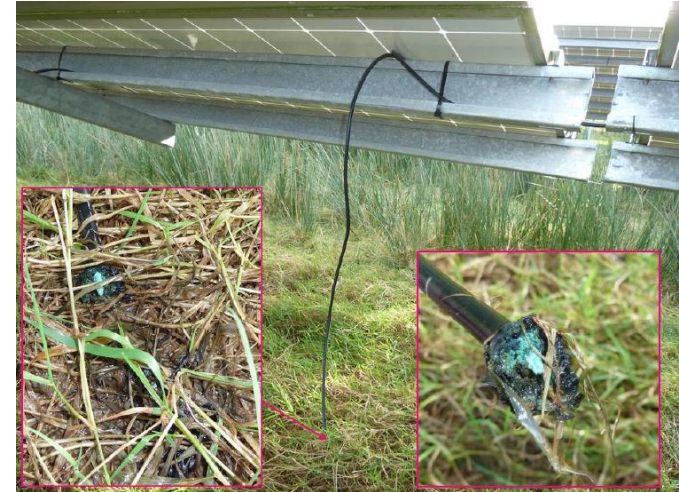
Many string connectors could easily be turned by hand on the string cable which suggests that the type of gasket and its compressing cage was not chosen according to the outer cable diameter.

4.2.1 Field assembled connectors and string cables

Again, the Sunbolts-compatible connectors of the string (homerun) cables were often found to be assembled in an inappropriate manner with damaged or skewed nuts und easily turnable by hand:



Fig. 4-14: string connector on negative pole of string 0205-05



Failures in PV systems – Case study

Site location: LATAM
Size: > 500 MW
Inspection: < 6 months after site completion



Failure pattern

- Broken/ burned connectors (several per week)
- Low-voltage at inverter caused by connectors

Consequences

- Performance loss (downtimes)
- Extra service/ repair cost
- Connector insurance claim to module maker and warranty claim to EPC for un-proper installation
- “Hand-over” to O&M company postponed

Solution




- Replacing failed connectors → change of complete system cabling?

Financial impact

- No string level monitoring, irradiance sensor not functioning
- **Downtimes/ service & repair cost?**

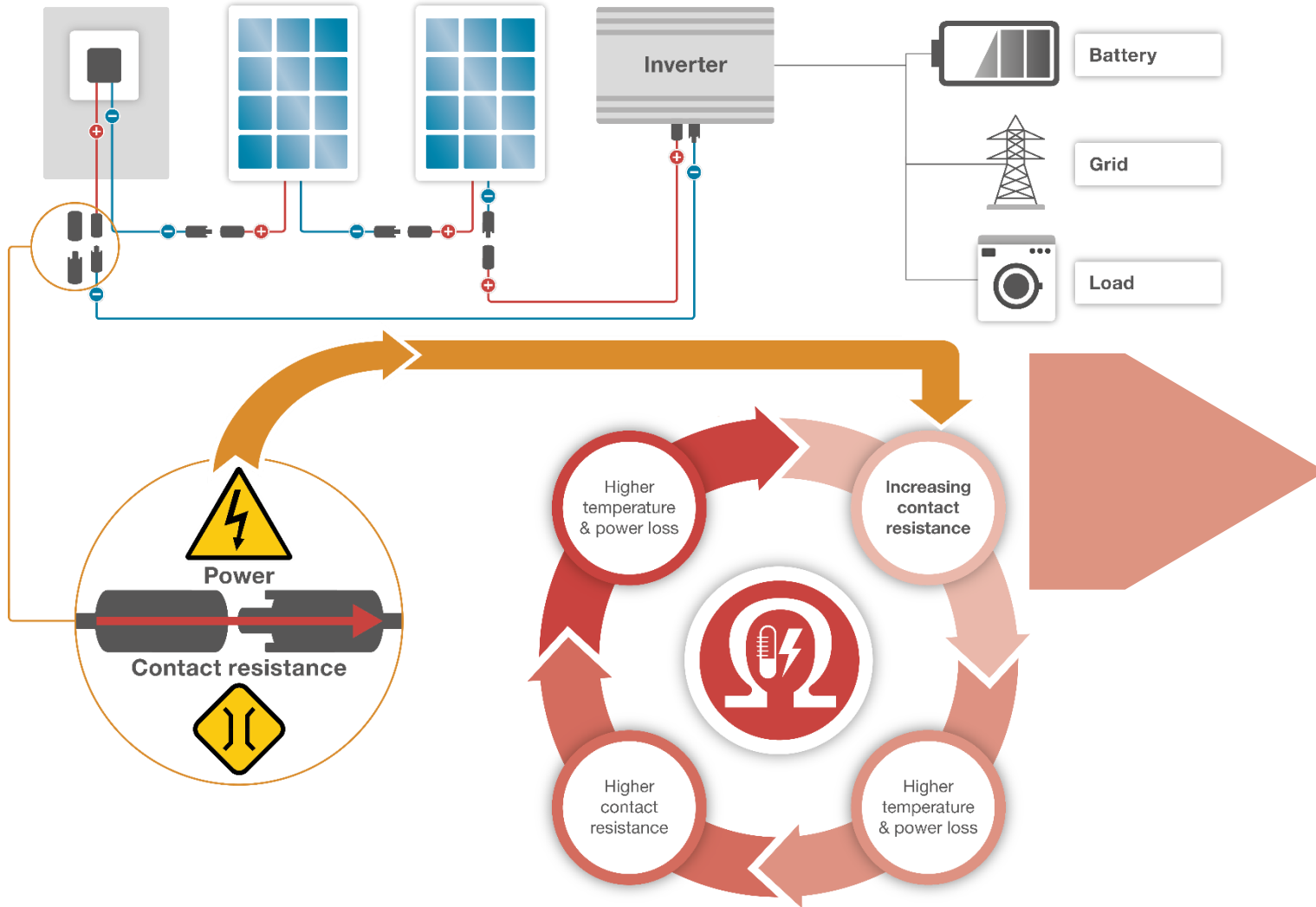
Failures in PV systems – Connector failure due to cross-connection

100MW system - 3.112 panels affected so far






-  No physical damage, but high temperature
-  Mechanical damage, but electrically conducting with high temperature
-  String failure due to completely broken connection mechanically and electrically



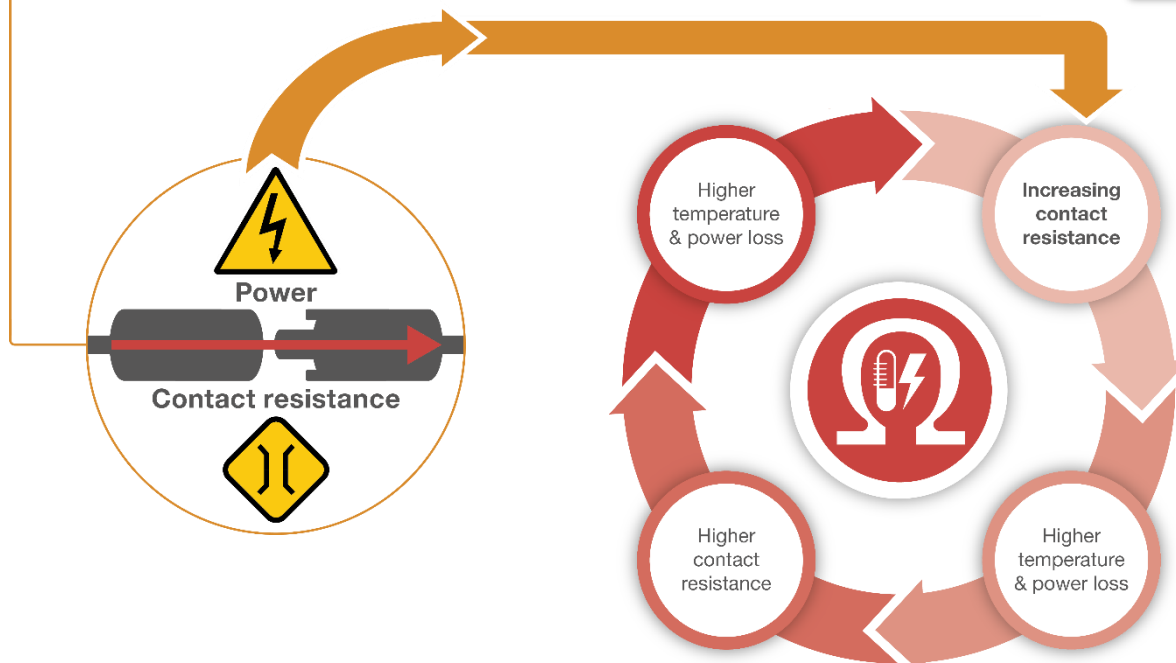
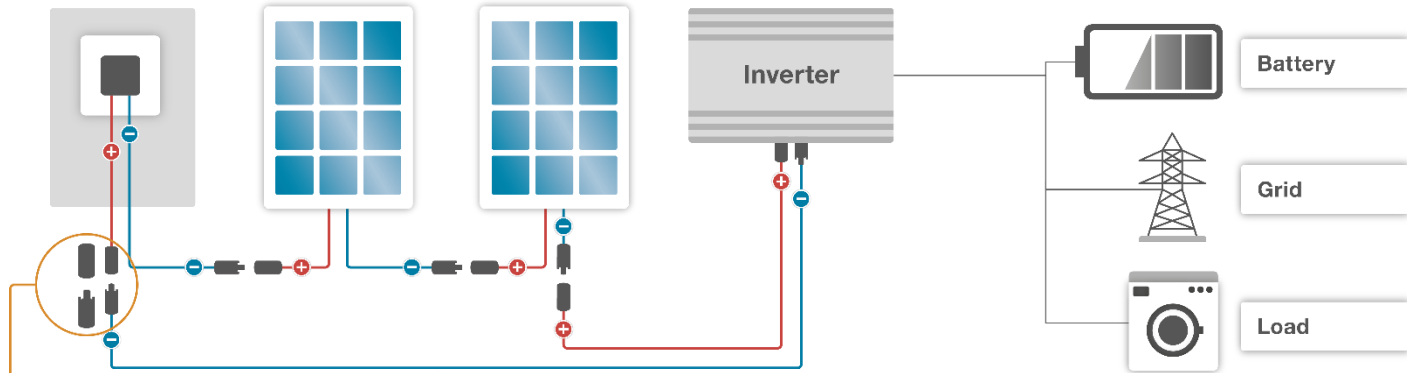
Why connectors (eBoS) can have this big impact



Consequences

-  High risk for (partial) connector failures
-  Performance losses, higher PPM-rates and downtimes of modules, strings or plants
-  High service/maintenance and spare part costs for repairing
-  Hotspots and fire in PV system and reconstruction costs
-  High costs for legal disputes due to undefined liabilities

Why connectors (eBoS) can have this big impact

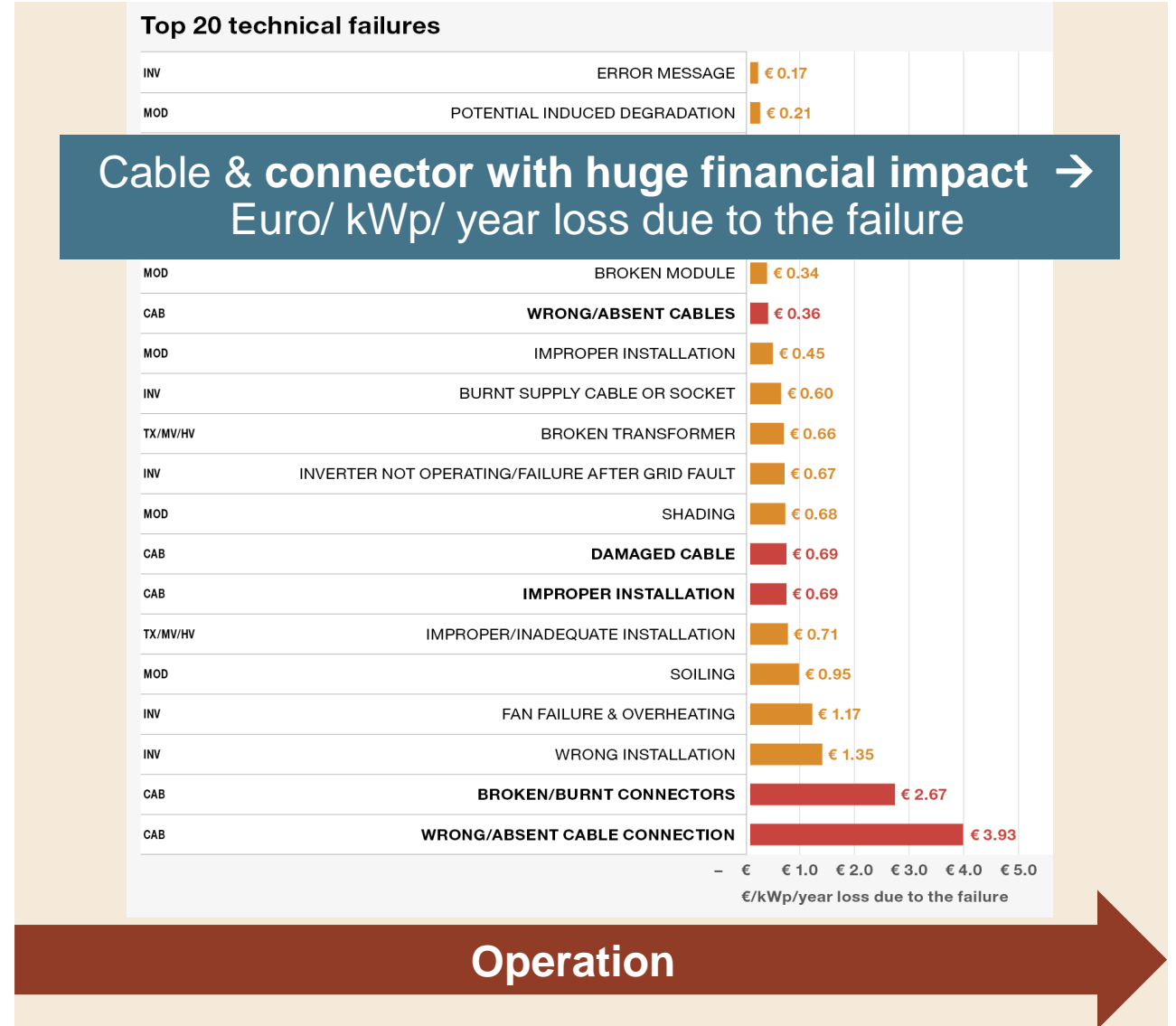
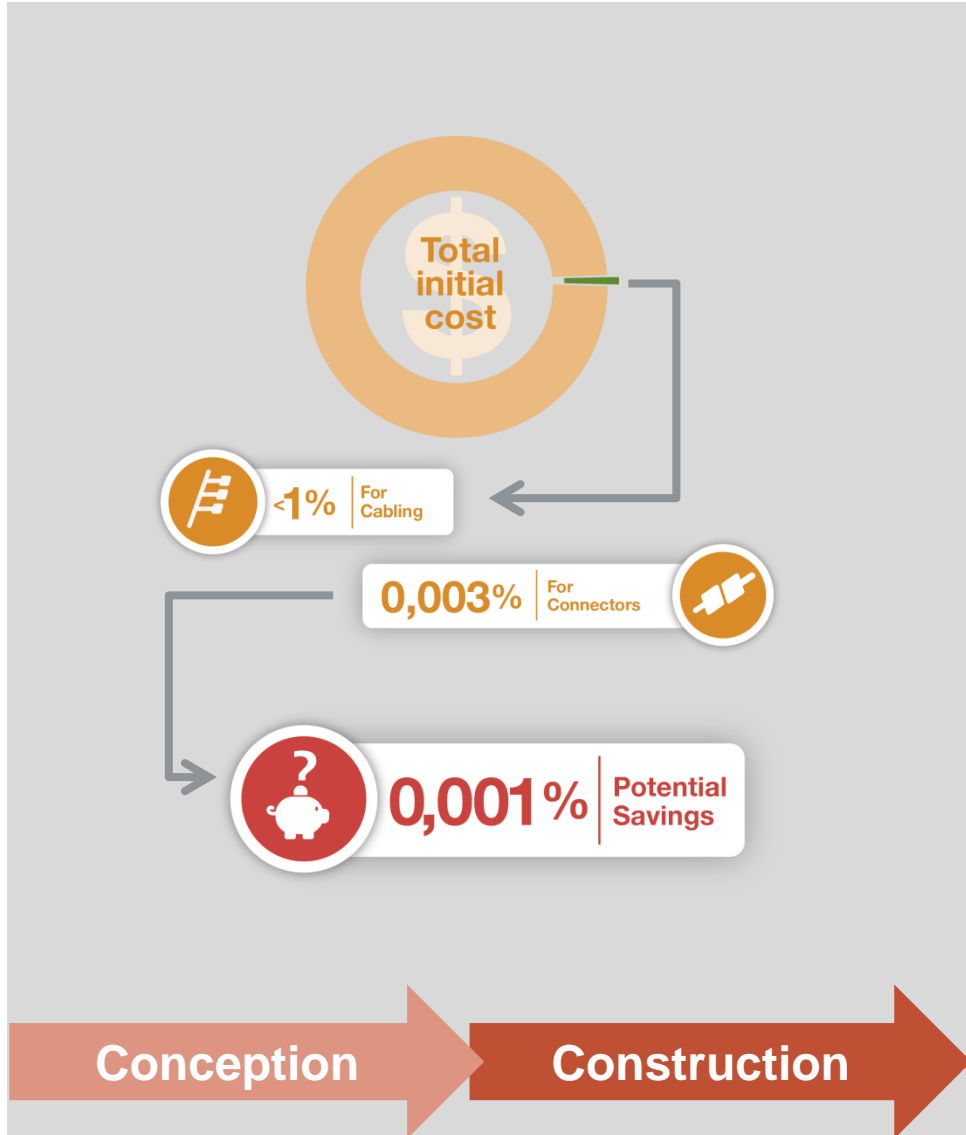


Constant low contact resistance

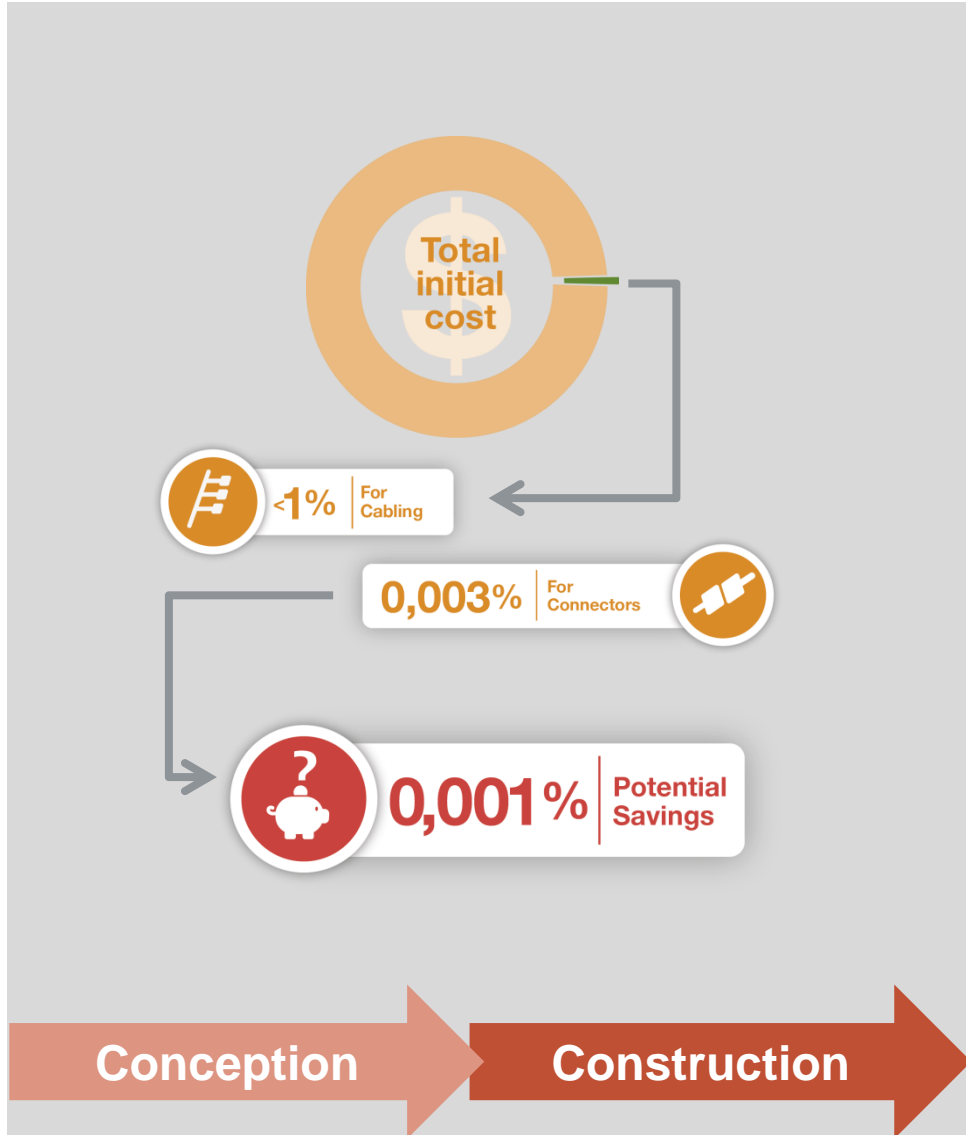
=

Long-term reliability and efficiency

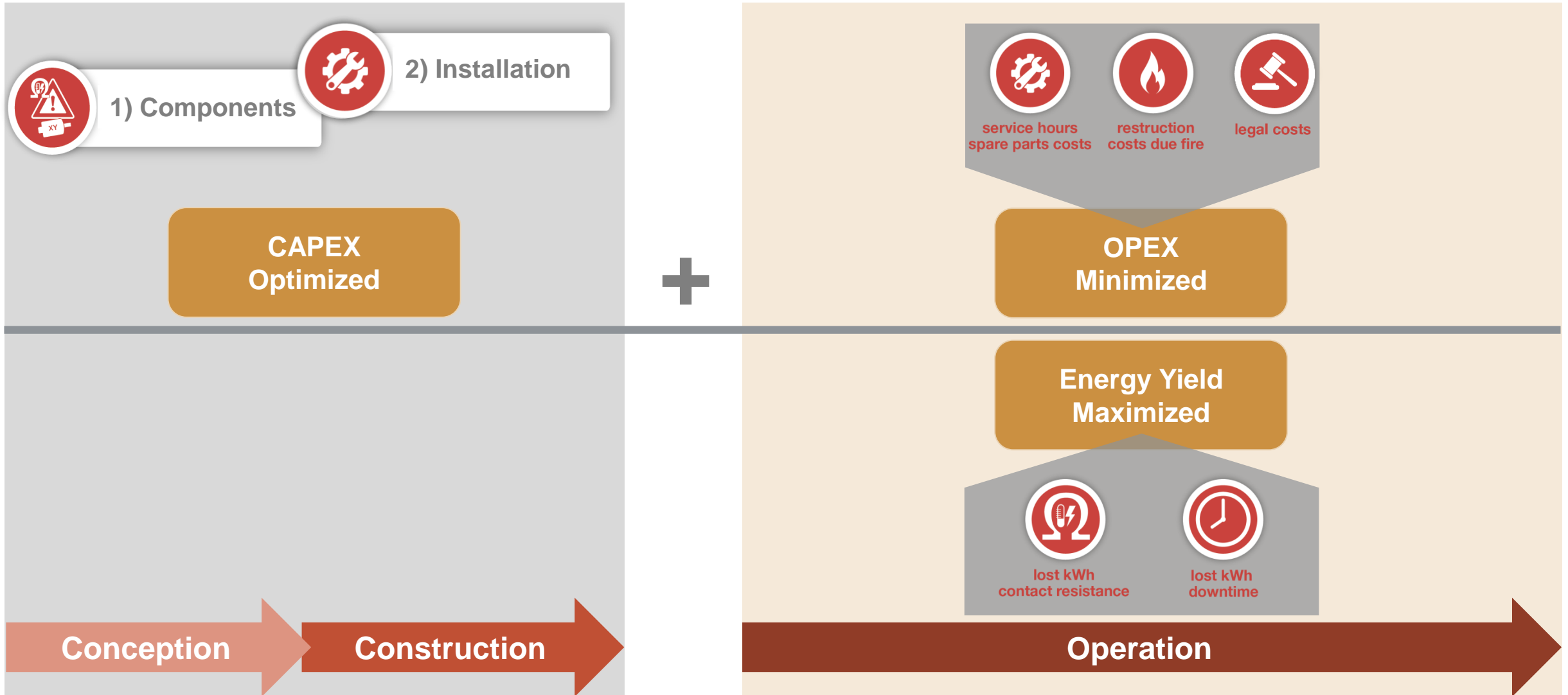
Small components. Big impact.



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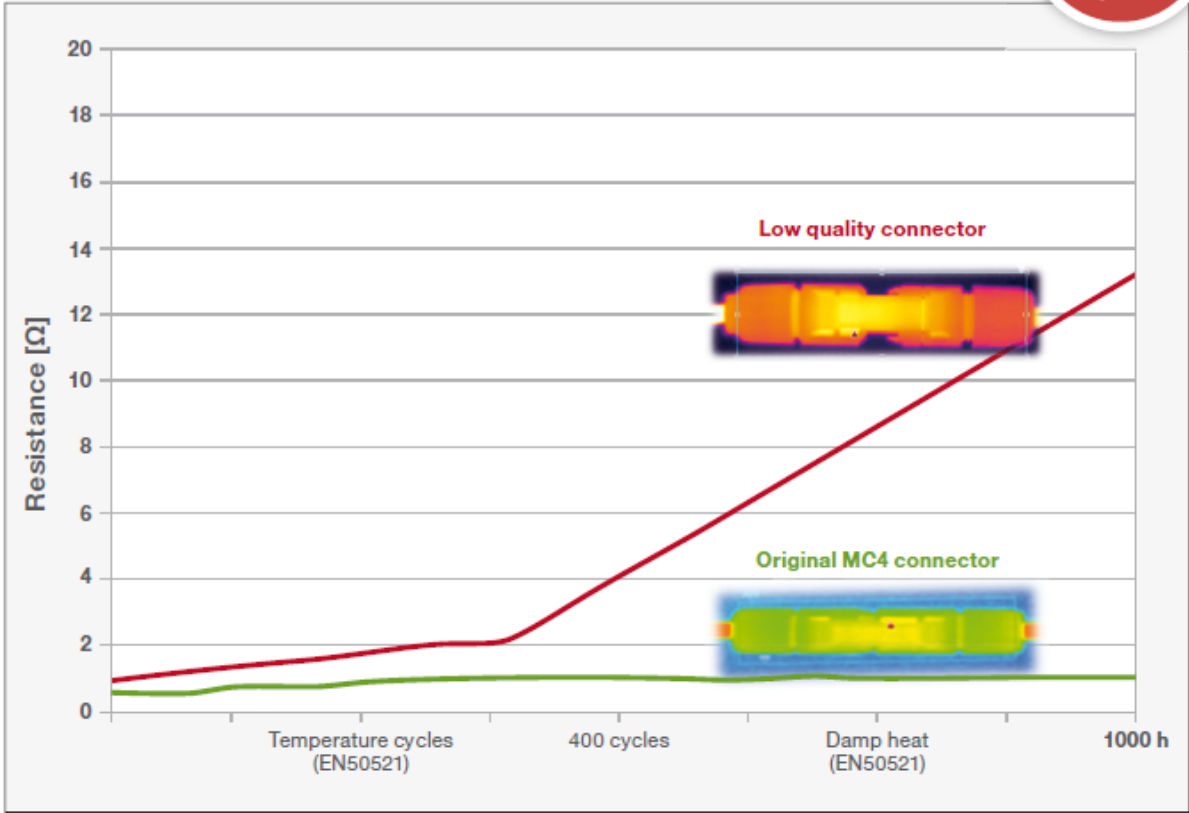


Leverage on LCOE (Levelized Cost of Energy)








1) Component Quality – Contact Resistance

Initial Measurements and after TCT/DHT



Consequences

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1) Component Quality – The PV DC Connector: a unique use case

Long lasting durability

- Life time expectancy

Harsh Environmental exposure

- Wide Temperature Range
- Outdoor / Weathering (Uncontrolled environment)

Excessive Mechanical stress

- Vibrations / Heavy impacts
- Wear / Fretting

Care-free operation & maintenance

- Unattended when in operation
- No regular inspection when in operation
- Inaccessibility of the product when installed

Challenging Safety Requirements

- Danger of electric shock
- Electric arcs and fire hazards

Demanding Product Design

- Smallest dimensional footprint
- Field assembly
- Cost effective design
- Galvanic compatibility

High Performance and reliability

- Low energy loss through-out product lifetime

Technical Risks
Economic Risks

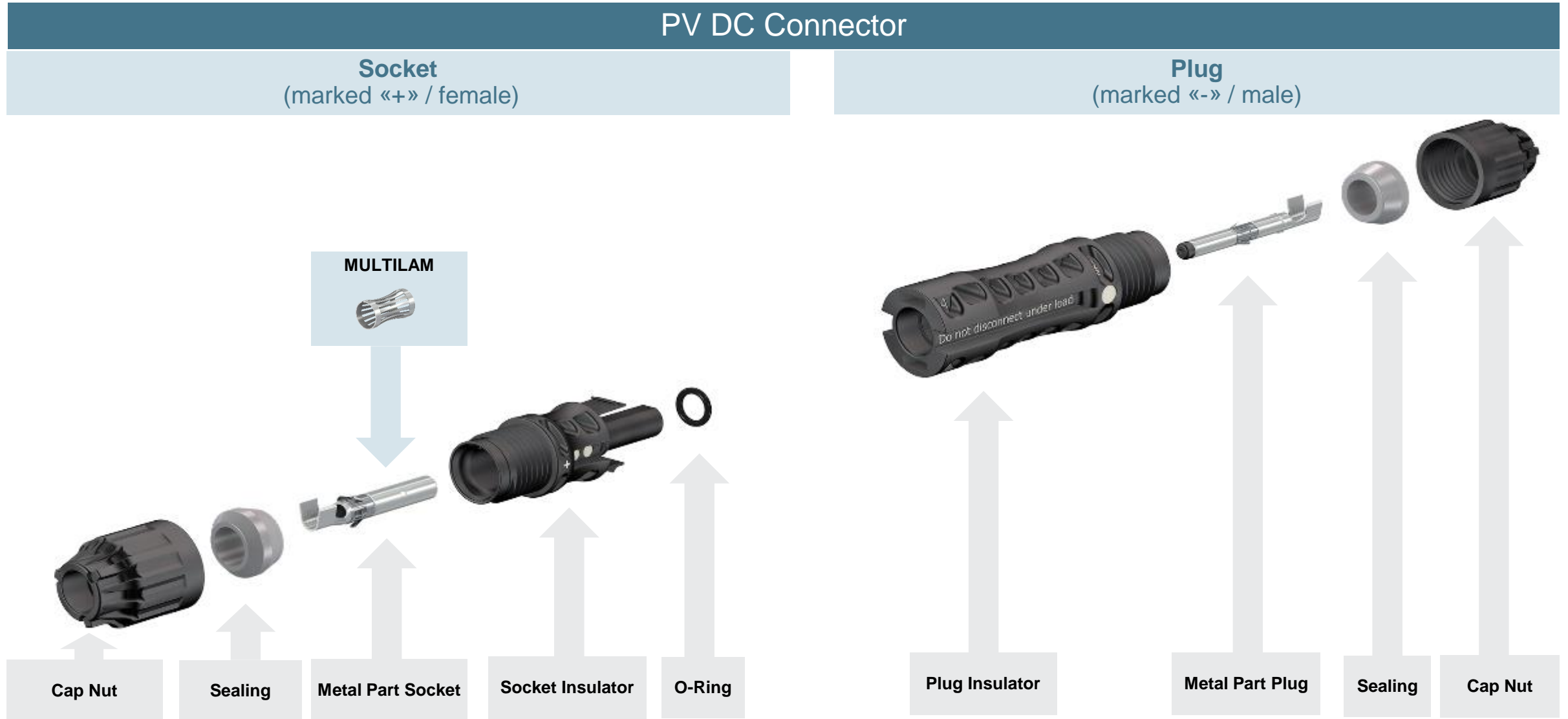
High
Quality
Product



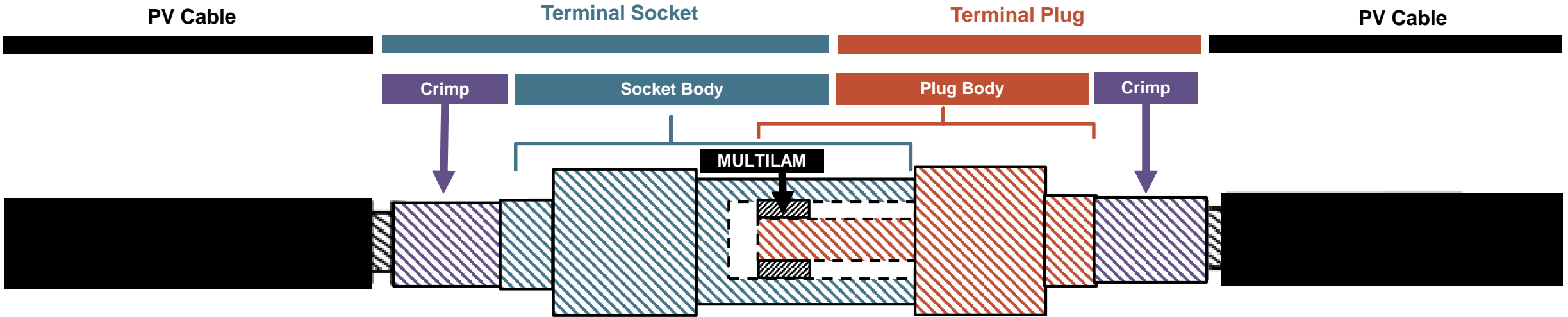
Industry Target

- Safe
- Reliable
- Cost-effective

1) Component Quality – PV DC Connector



1) Component Quality – Resistances within a PV DC connector



1

Contact Resistance as per IEC 60512-2-2

Focus: Displays quality of electrical contact between plug & socket, value is independent of conductor cross-section size
 Description: Terminal-to-Terminal-Resistance, excl. resistance of crimp and cable,
 Typical value: <0.25 mΩ
 Measurement points are placed on body of socket and plug
 Use case: Data sheets, catalogues, assembly instructions



$$R_1 = R_{BodyS} + R_{MULTILAM} + R_{BodyP}$$

2

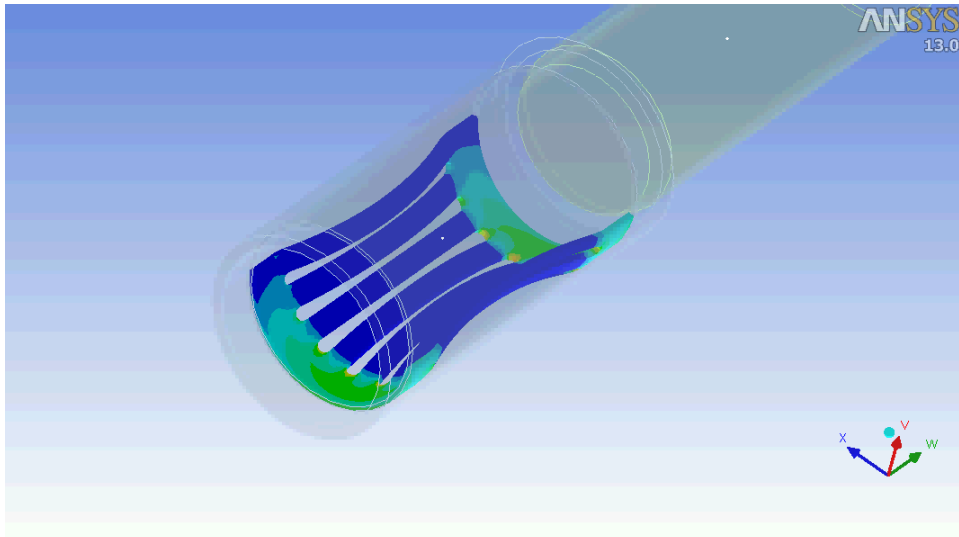
Contact Resistance as per IEC 62852

Focus: Considers crimp quality, value is dependent of conductor cross-section size
 Description: Includes crimp resistance and cable resistance
 Typical value:
 2,5mm²: <0.9 mΩ
 4,0mm²: <0.7 mΩ
 6,0mm²: <0.6 mΩ
 10,0mm²: <0.4 mΩ
 Measurement points are placed on cable conductor
 Use case: Certification laboratories

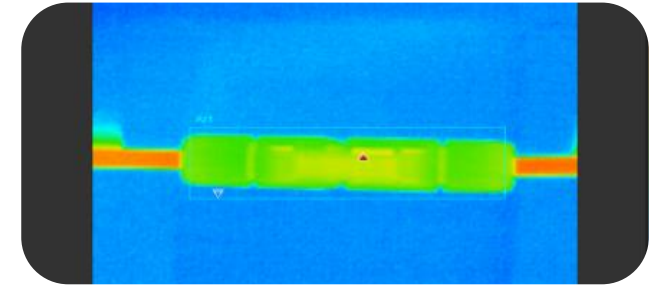


$$R_2 = (R_{CableS} + R_{CrimpS} + R_{BodyS} + R_{MULTILAM} + R_{BodyP} + R_{CrimpP}) - 2X(R_{Cable})$$

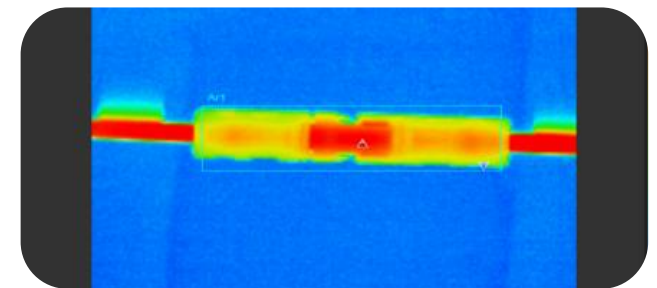
1) Component Quality – Stäubli Technology: MULTILAM



MC4 (MULTILAM Technology)



Competitor Product (no MULTILAM)



Scale

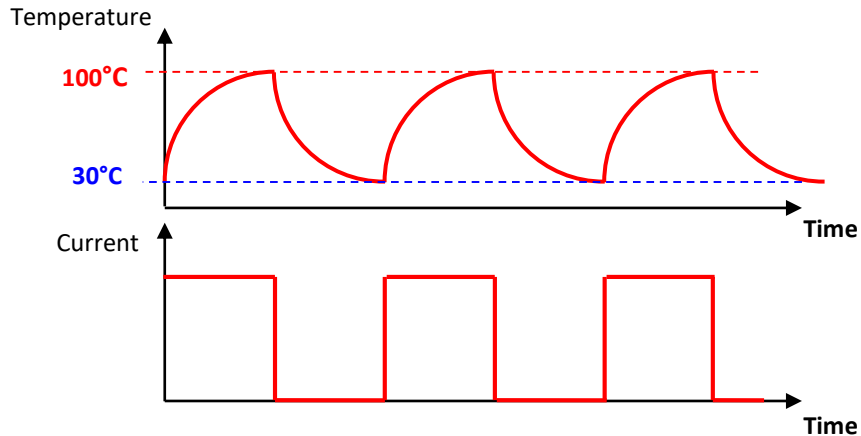
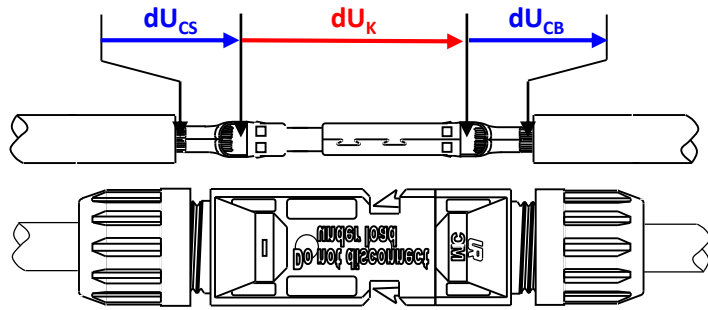
$T_{Min} = 25^{\circ}C$

$T_{Max} = 45^{\circ}C$

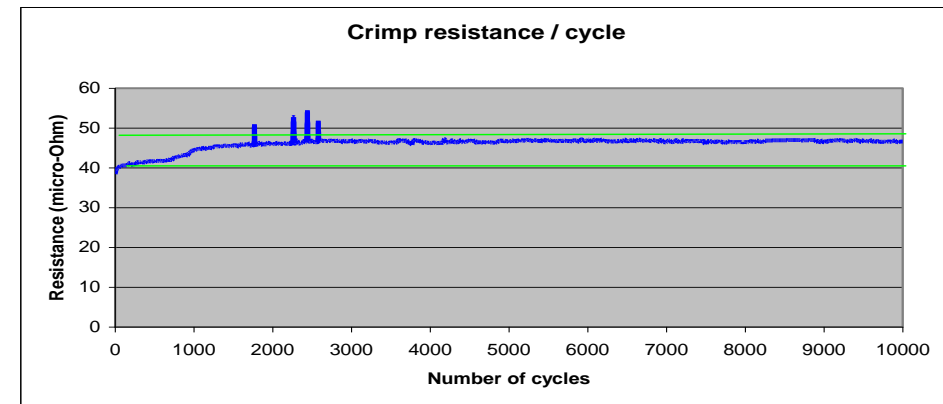
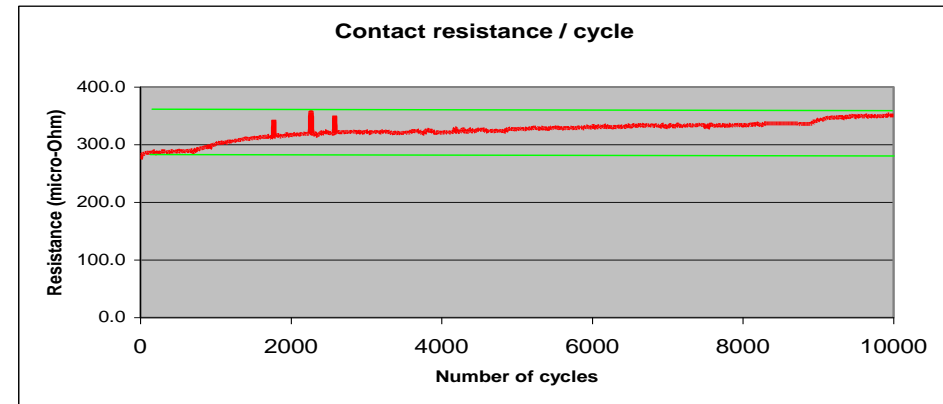
Measurements acc. to IEC60512-5-1

1) Component Quality – Contact Resistance: Laboratory Results

Test Setup



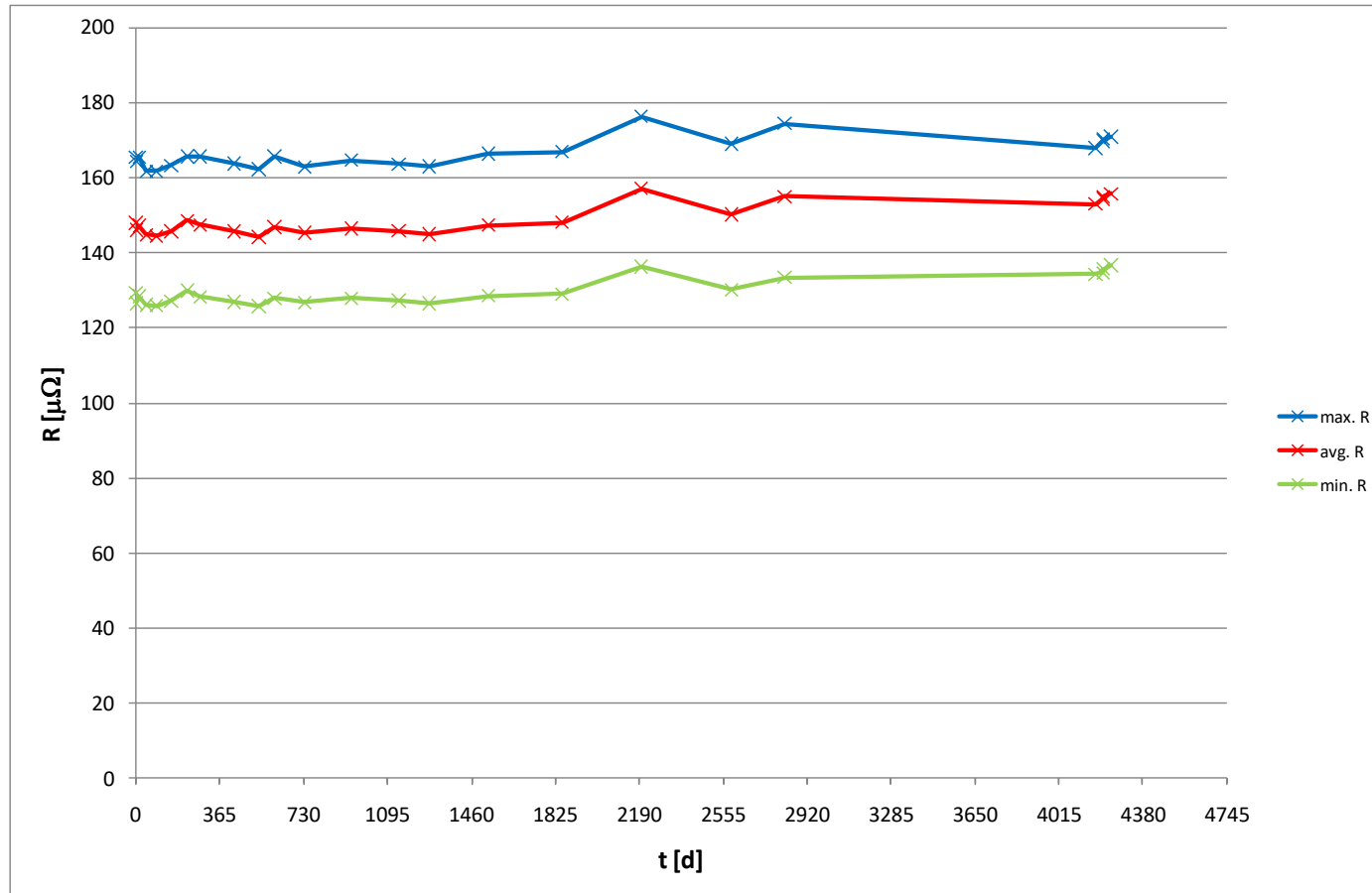
Test Result



10'000 cycles representing ~ 20 years!

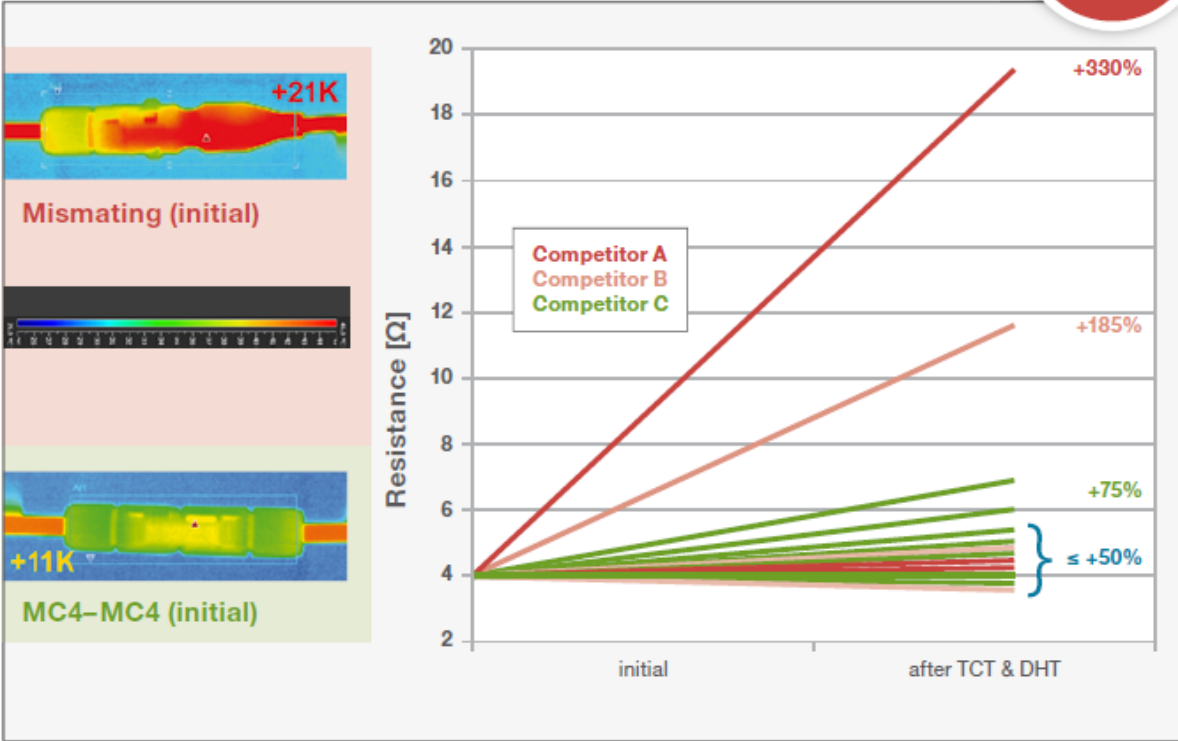
1) Component Quality – Contact Resistance: Field Results

Long-term experience – 12 years on the roof monitoring



2) Installation – Cross-Connection

Initial Measurements and after TCT/DHT



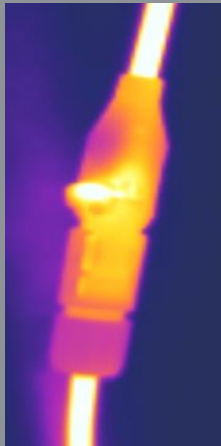
Consequences

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2) Installation – Cross-Connection

After 5min: heavily smoking
 Power loss: 800W
 Temperature: >200 °C

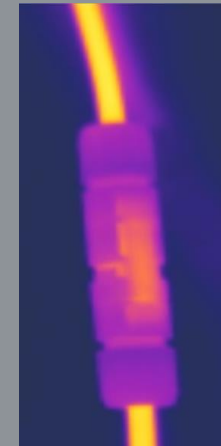


100A

200 °C
 150 °C
 100 °C
 50 °C



After 5min: no defects
 Power loss: 73W
 Temperature: 135 °C



100A

Technical risk

- Caused by: Different technology, dimensions, product-material, production-process, -capacity, etc.

Legal risk

- NO certification:** IEC 62852 (EN50521) and UL 6703 product norm resp. UL 1703 module norm
- NO compatibility:** IEC 62548 installation norm, Statement TUV Rheinland
- Liability? → NO warranty/guarantee!**



2) Installation – Cross-Connection: Normative References

Global Installation Norm: IEC 62548 – PV Arrays

9.3.9 Plugs, sockets and connectors

Plugs and socket connectors mated together in a PV system shall be of the same type from the same manufacturer. I.e. a **plug from one manufacturer and a socket from another manufacturer or vice versa shall not be used to make a connection.**



UL Standard 6703 – PV Connectors

Conditions of acceptance

“...have been investigated as acceptable for assembly in the field by qualified electricians with factory provided tooling.

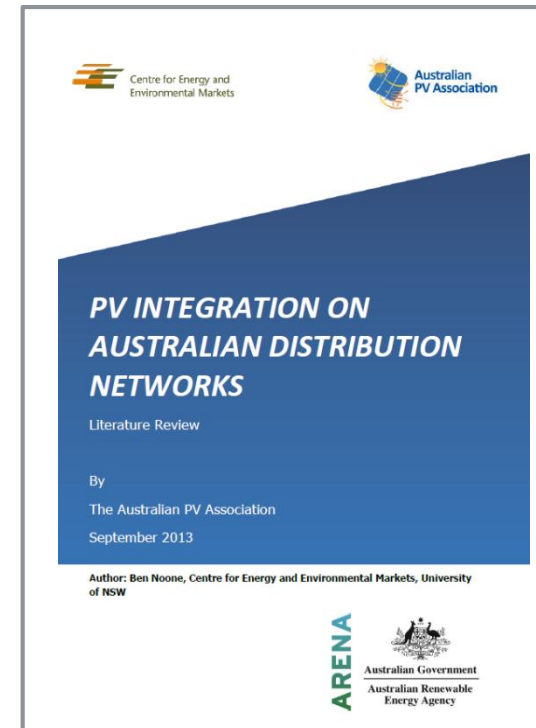
“These devices have only been assessed for UL Recognition with specific types of **mated connectors within their product family.**

They have not been assessed to operate with any other similar devices from any other manufacturer.”



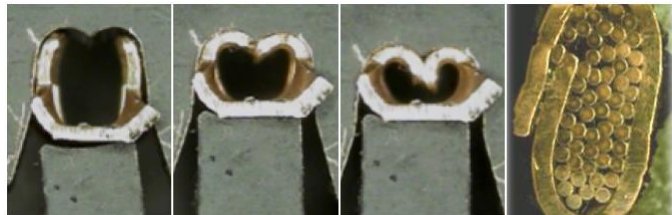
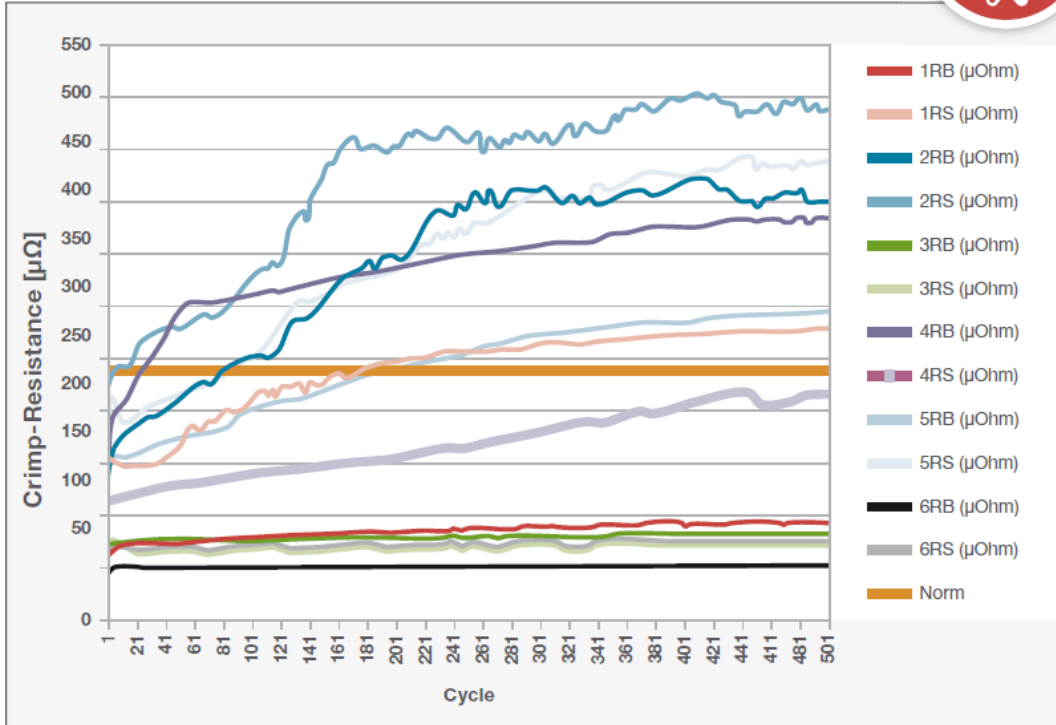
National Guidelines

- Australia, France, Brazil & Turkey

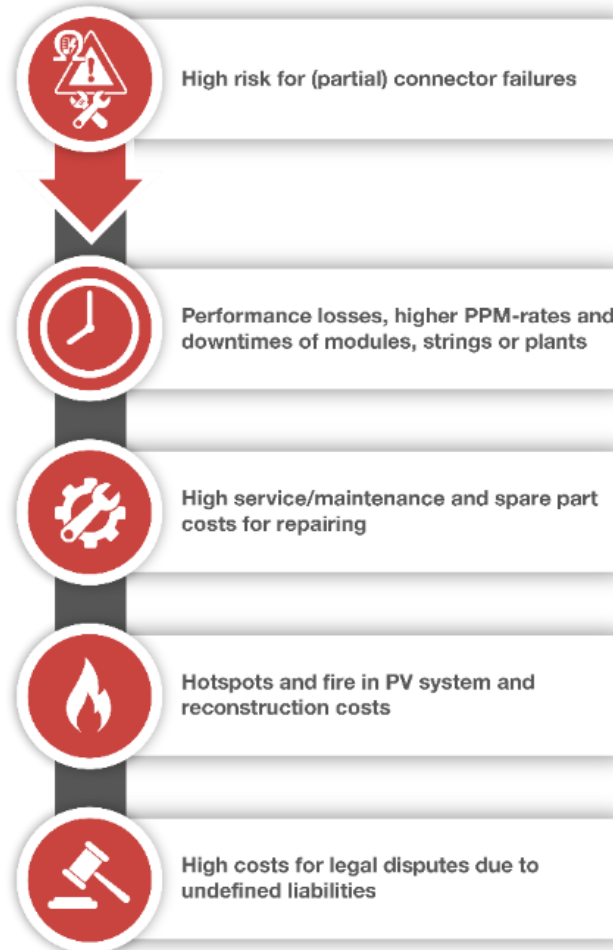


2) Installation – Defective Cable Management (Crimping)

Initial Measurements and after TCT



Consequences



2) Installation – Common mistakes (Examples)

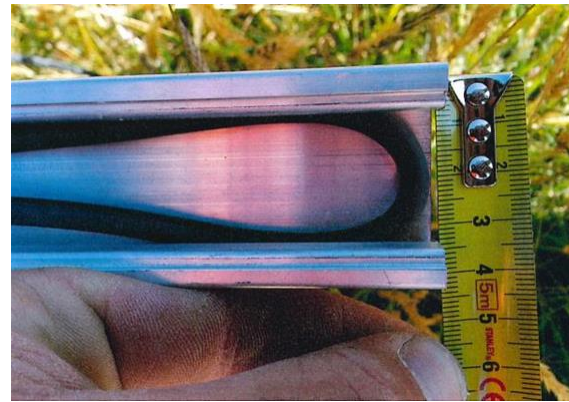
Connectors/ cables directly placed on roof or ground surface



Cable permanently exposed to water



Excessive tension and sharp bending radius



Error in product selection and configuration



Financial and safety risk

Laboratory testing:
Connections 5 years after commissioning



Insulation Resistance

$R > 400 \text{ M}\Omega$

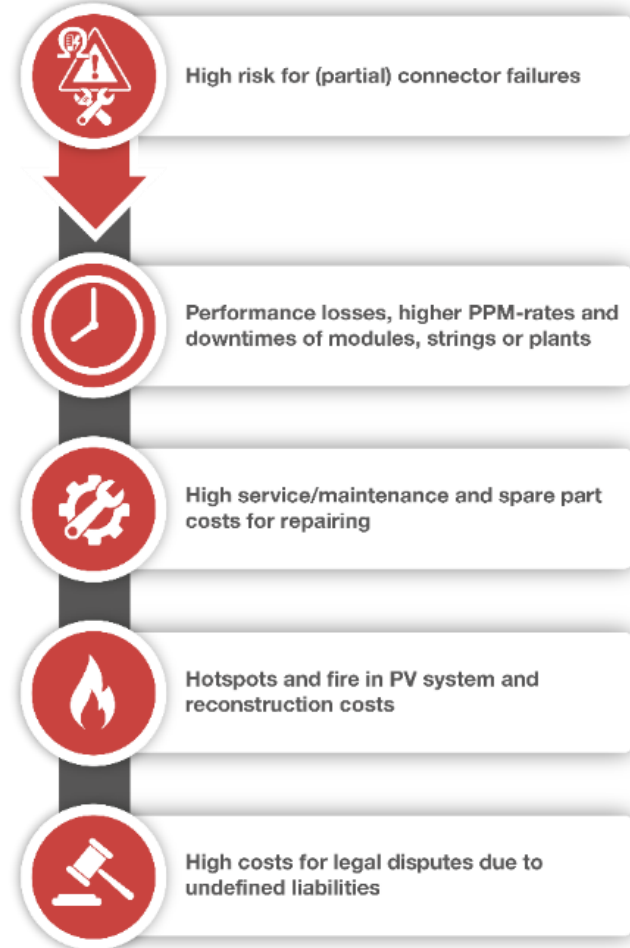
Original x Original \emptyset	1660,00 $\text{M}\Omega$
Cross-Connection \emptyset	0,06 $\text{M}\Omega$

Contact Resistance

$R \emptyset 530 \mu\Omega$

Original x Original \emptyset	532 $\mu\Omega$
Cross-Connection \emptyset	6841 $\mu\Omega$

Consequences



Summery – Set the foundation right at the very early stages

Impact on LCOE →

Optimized CAPEX

+

Minimized OPEX

/

Higher Energy Yield

Operation

Conception

Construction

- **System design, specifications, contracts** → LCOE balance
- **Components** → performance, processes, partner, track record, reputation, bankability, factory audit
- **Partners** → quality approach, educated technical staff (sub-contractors)

- **Pre-assembled** (factory)
- **Installation norm** → cross-connection, tools, crimping
- **Assembly instructions**
- **Cable-management**
- **Construction supervision** (coordination)

- **Monitoring**
- (Preventive) **Inspection** visual/ thermal
- **Laboratory Testing**
- **Local support/ expertise**
- Spare part management