Small components. Big impact.
Cabling of PV installations – Key factors for a successful long-time reliability

PV Magazine Insight on Quality– @ All Energy Australia
YOUR BANKABLE PARTNER

Stäubli Group – three activities, four divisions

> 125 years experience

> 5500 employees in 29 countries

> 300 GW PV connected

Formerly: Multi-Contact MC

Robotics

Connectors
- Fluid Connectors
- Electrical Connectors

Textile
CORPORATE BANKABILITY

Your bankable partner – More than “just” a product

Products

- Proven reliability
- Original MC4 sets the standard
- Less risk, higher return
- In-house production
- Testing beyond the norm

Company

- Over 125 years of experience
- Market leader
- Multinational Swiss company
- Over 200 GW PV capacity
- Industrial know-how

Service

- Customer service
- Global presence
- Product availability
- Guarantee
- Education

Stäubli - Small Components. Big Impact.
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
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

<table>
<thead>
<tr>
<th>Failure Description</th>
<th>Economic Impact (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERROR MESSAGE</td>
<td>0.17</td>
</tr>
<tr>
<td>POTENTIAL INDUCED DEGRADATION</td>
<td>0.21</td>
</tr>
<tr>
<td>MAIN SWITCH OPEN &amp; DOES NOT RECLOSE AUTOMATICALLY</td>
<td>0.22</td>
</tr>
<tr>
<td>GLASS BREAKAGE</td>
<td>0.27</td>
</tr>
<tr>
<td>TRACKER FAILURE</td>
<td>0.31</td>
</tr>
<tr>
<td>BROKEN MODULE</td>
<td>0.34</td>
</tr>
<tr>
<td>WRONG/ABSENT CABLE</td>
<td>0.36</td>
</tr>
<tr>
<td>IMPROPER INSTALLATION</td>
<td>0.45</td>
</tr>
<tr>
<td>BURNT SUPPLY CABLE OR SOCKET</td>
<td>0.60</td>
</tr>
<tr>
<td>BROKEN TRANSFORMER</td>
<td>0.66</td>
</tr>
<tr>
<td>INVERTER NOT OPERATING/Failure AFTER GRID FAULT</td>
<td>0.67</td>
</tr>
<tr>
<td>SHADING</td>
<td>0.68</td>
</tr>
<tr>
<td>DAMAGED CABLE</td>
<td>0.69</td>
</tr>
<tr>
<td>IMPROPER INSTALLATION</td>
<td>0.69</td>
</tr>
<tr>
<td>IMPROPER/INADEQUATE INSTALLATION</td>
<td>0.71</td>
</tr>
<tr>
<td>SOILING</td>
<td>0.95</td>
</tr>
<tr>
<td>FAN FAILURE &amp; OV/ERHEATING</td>
<td>1.17</td>
</tr>
<tr>
<td>WRONG INSTALLATION</td>
<td>1.35</td>
</tr>
<tr>
<td>BROKEN/BURNT CONNECTORS</td>
<td>2.67</td>
</tr>
<tr>
<td>WRONG/ABSENT CABLE CONNECTION</td>
<td>3.90</td>
</tr>
</tbody>
</table>

*www.solarbankability.org
Failures in PV systems – You can’t manage the unknown

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 – 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

Constant low contact resistance

= Long-term reliability and efficiency
## PROJECT BANKABILITY

Small components. Big impact.

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

<table>
<thead>
<tr>
<th>Failure Description</th>
<th>Euro/kWp/year Loss</th>
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<tbody>
<tr>
<td>Broken Module</td>
<td>€0.34</td>
</tr>
<tr>
<td>Wrong/Absent Cables</td>
<td>€0.36</td>
</tr>
<tr>
<td>Improper Installation</td>
<td>€0.45</td>
</tr>
<tr>
<td>Burnt Supply Cable or Socket</td>
<td>€0.60</td>
</tr>
<tr>
<td>Broken Transformer</td>
<td>€0.66</td>
</tr>
<tr>
<td>Inverter Not Operating/Failure After Grid Fault</td>
<td>€0.67</td>
</tr>
<tr>
<td>Shading</td>
<td>€0.68</td>
</tr>
<tr>
<td>Damaged Cable</td>
<td>€0.69</td>
</tr>
<tr>
<td>Improper Installation</td>
<td>€0.69</td>
</tr>
<tr>
<td>Improper/Inadequate Installation</td>
<td>€0.71</td>
</tr>
<tr>
<td>Soiling</td>
<td>€0.95</td>
</tr>
<tr>
<td>Fan Failure &amp; Overheating</td>
<td>€1.17</td>
</tr>
<tr>
<td>Wrong Installation</td>
<td>€1.35</td>
</tr>
<tr>
<td>Broken/Burnt Connectors</td>
<td>€2.67</td>
</tr>
<tr>
<td>Wrong/Absent Cable Connection</td>
<td>€3.93</td>
</tr>
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### Top 20 Technical Failures

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<th>Failure Type</th>
<th>Cost</th>
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<tr>
<td>Error Message</td>
<td>€0.17</td>
</tr>
<tr>
<td>Potential Induced Degradation</td>
<td>€0.21</td>
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</tbody>
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PROJECT BANKABILITY

Small components. Big impact.

Conception  Construction  Operation

- Original Stäubli MC4 Connector
- Low quality connectors

- lost kWh contact resistance
- lost kWh downtime
- service hours spare parts costs
- restriction costs due fire
- legal costs

1% For Cabling
0.003% For Connectors
0.001% Potential Savings

11/5/2020
Leverage on LCOE (Levelized Cost of Energy)

1) Components
- CAPEX Optimized

2) Installation
- OPEX Minimized
- Energy Yield Maximized

- service hours
- spare parts costs
- restriction costs due fire
- legal costs
- lost kWh contact resistance
- lost kWh downtime
1) Component Quality – Contact Resistance

Initial Measurements and after TCT/DHT

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
1) Component Quality – Stäubli Technology: MULTILAM

MC4 (MULTILAM Technology)

Competitor Product (no MULTILAM)

Scale
\[ T_{\text{Min}} = 25^\circ\text{C} \]
\[ T_{\text{Max}} = 45^\circ\text{C} \]

Measurements acc. to IEC60512-5-1
2) Installation – Cross-Connection

**Initial Measurements and after TCT/DHT**

- Mismating (initial)
- MC4-MC4 (initial)

**Consequences**

- High risk for (partial) connector failures
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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
### Laboratory testing:
Connections 5 years after commissioning

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>Insulation Resistance</th>
<th>Contact Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original x Original Ø</td>
<td>R &gt; 400 MΩ</td>
<td>R Ø 530 µΩ</td>
</tr>
<tr>
<td>Ø</td>
<td>1660,00 MΩ</td>
<td>532 µΩ</td>
</tr>
<tr>
<td>Cross-Connection Ø</td>
<td>0,06 MΩ</td>
<td>6841 µΩ</td>
</tr>
</tbody>
</table>

**Consequences**
- High risk for (partial) connector failures
- Performance losses, higher PPM-rates and downtimes of modules, strings or plants
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Summery – Set the foundation right at the very early stages

**Impact on LCOE**
- **Optimized CAPEX**

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

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

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