Reliability of Power Electronics in Renewable Energies:

Development, Qualification and System Design

Presented by Daniel Clemens, Reliability Technical Manager

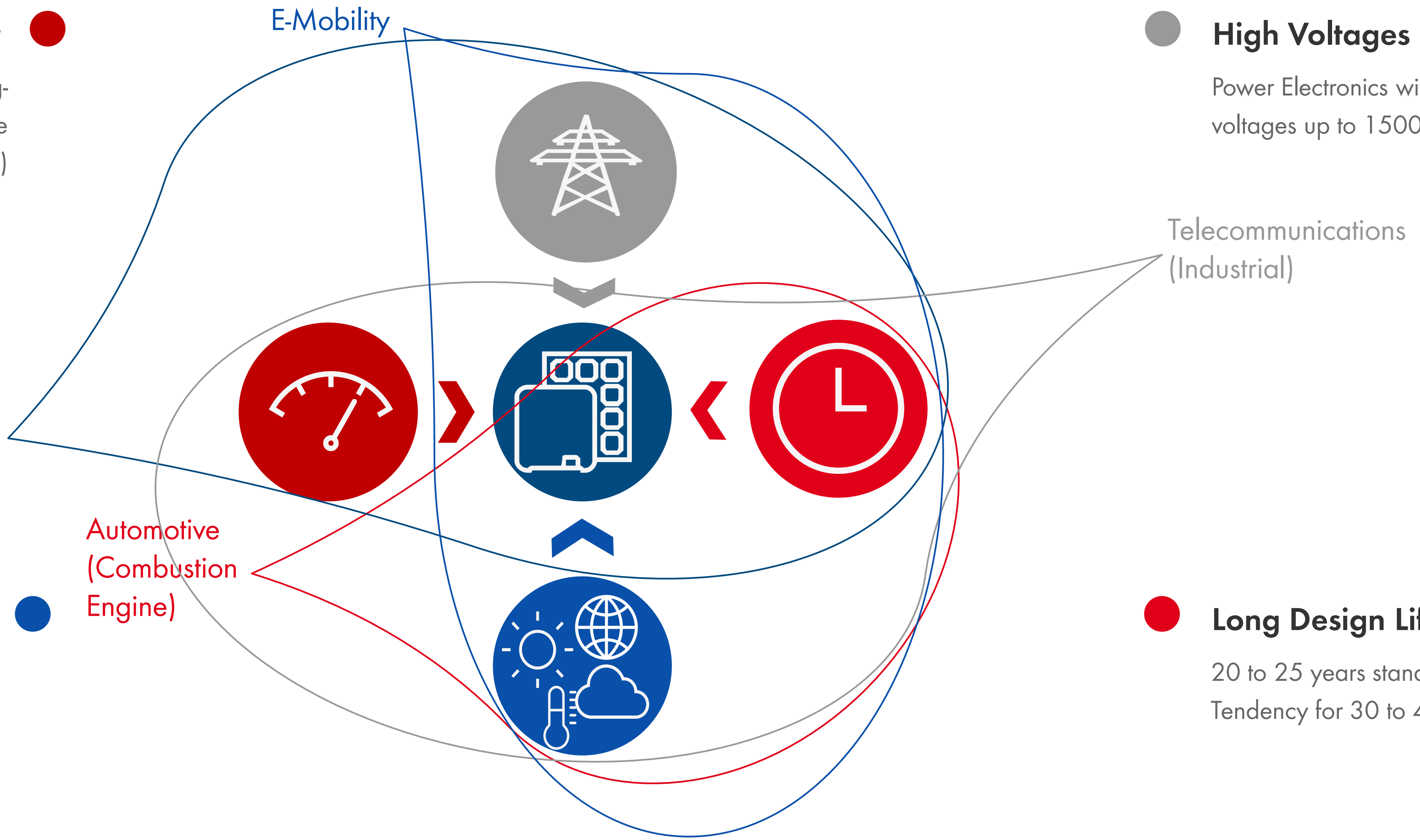
Unique Requirements for PV Inverters

High Load Factor

extremely high number of working-hours. Nowadays even at night time (Q at night)

High Voltages

Power Electronics with voltages up to 1500V



Outdoor Worldwide

The inverter needs to cope with all sorts of climates, rain, hail, dust, sandstroms, snow, elevated irradance, low/high temperatures

Long Design Lifetime

20 to 25 years standard.
Tendency for 30 to 40 years

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1 **Design For Reliability**
Component Design Aspects

2 **Size Matters**
System Design Aspects

3 **Module Level Power Electronics**
Reduce Parts

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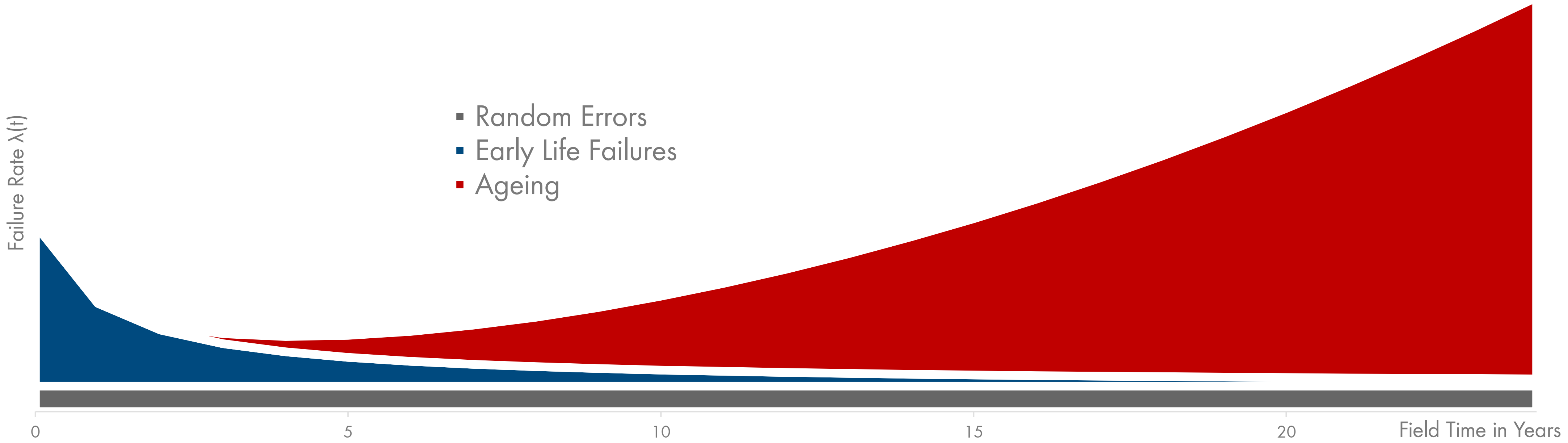
What leads to failures?



Random Errors

Dramatically overestimated (FIT Rate calculations are obsolete).

Cosmic Radiation is the only reported failure mechanism.

Early Life Failures

To cope with by

- Stable production process
- Effective product end test
- Incoming goods inspection

Ageing

Often referred to as "Design Failures" or "Series Failures".

Neither appear during final inspection nor during standard qualification tests.

Instead: **Acceleration of the reality necessary**

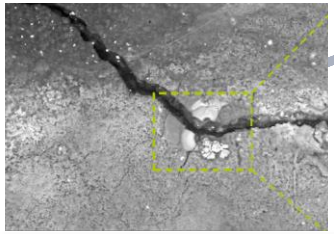
Design for Reliability by Accelerated Life Tests

Mission Profile

- Temperature
- Humidity
- Cycles
- other

Temperature	time in h per
0	32
10	1056
20	1900
30	2073
40	931
50	670
60	759
70	782
80	544
85	13

Aging Mechanism

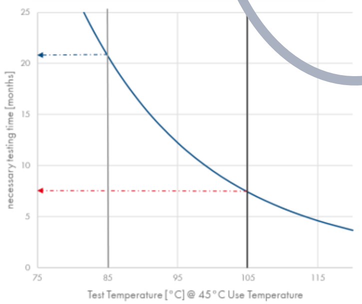


What kills the device?

- Growth of intermetallic phase
- Formation of cracks
- Ion transport
- Dentrites

Aging Model

- correlation between time and stress level
- How long to test at which stress level

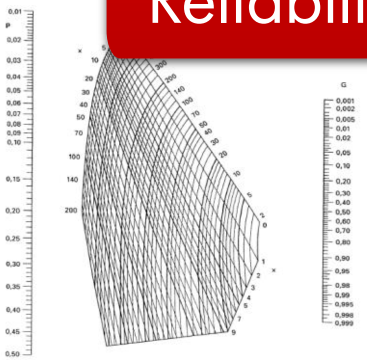


Aging Test

- Heat
- Cycles
- Humidity
- other

Demon-strated Reliability

- No. of tested components
- How many failures



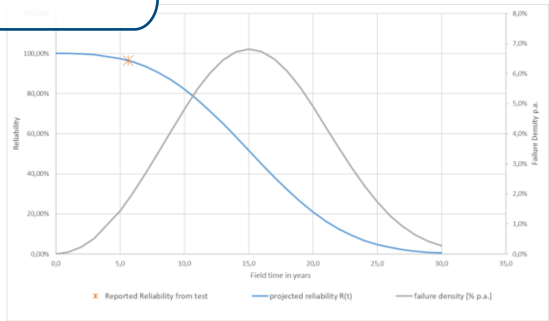
Failure Distribution

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$$

- during test
- literature
- previous test

Reliability Prognosis

- reliability over time



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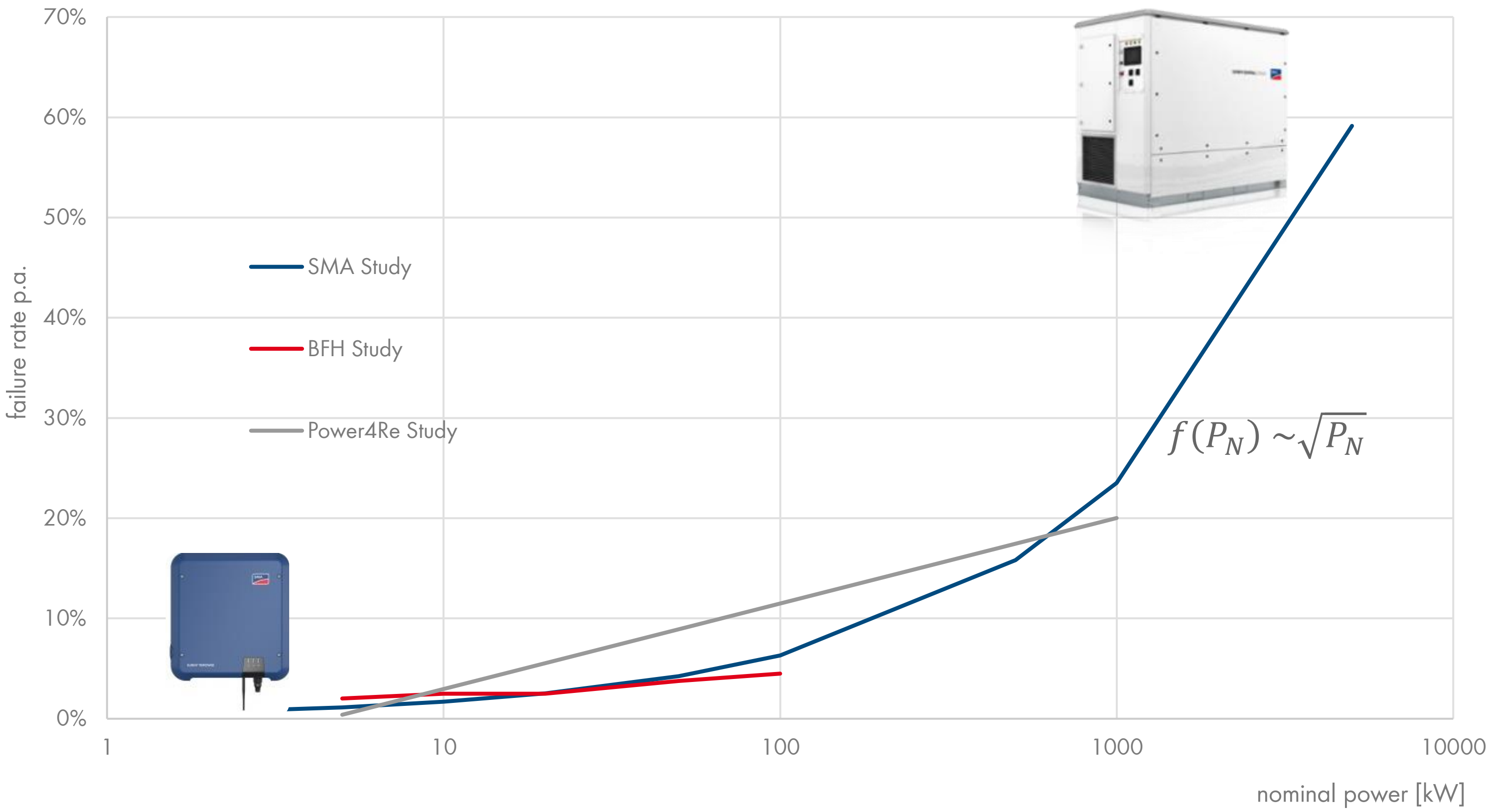
Failures as function of Inverter Nominal Power

Mean annual Failure rate over inverter nominal power



Mean annual Failure Rate increases over Inverter Power

Failure Rate rises slower than Power

100 x Power ⟹ 10 x Failures

BFH study: *Life Expectancy of PV Inverters and Optimizers in Residential PV Systems, Bern University of applied science – 2022*

Power4Re study: *Power4re – Zuverlässige Umrichter für die regenerative Energieversorgung, Fraunhofer Gesellschaft, 2020 – 2023*

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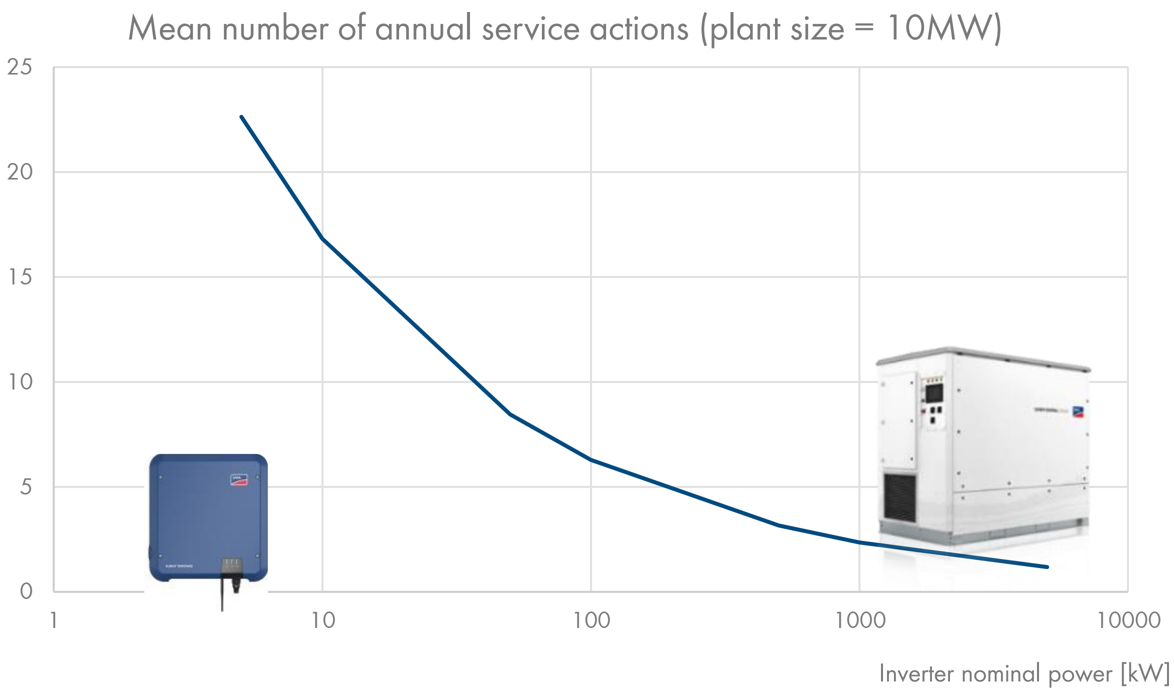


100 x Power
⟹ 90% Reduction of Service Actions

Mean annual number of service actions decreases with inverter power

For a constant plant size the mean annual number of service actions decreases.

Parts will only fail, if they are designed in.

Large inverters performe better due to the reduced number of components.

Effect on availability and revenue

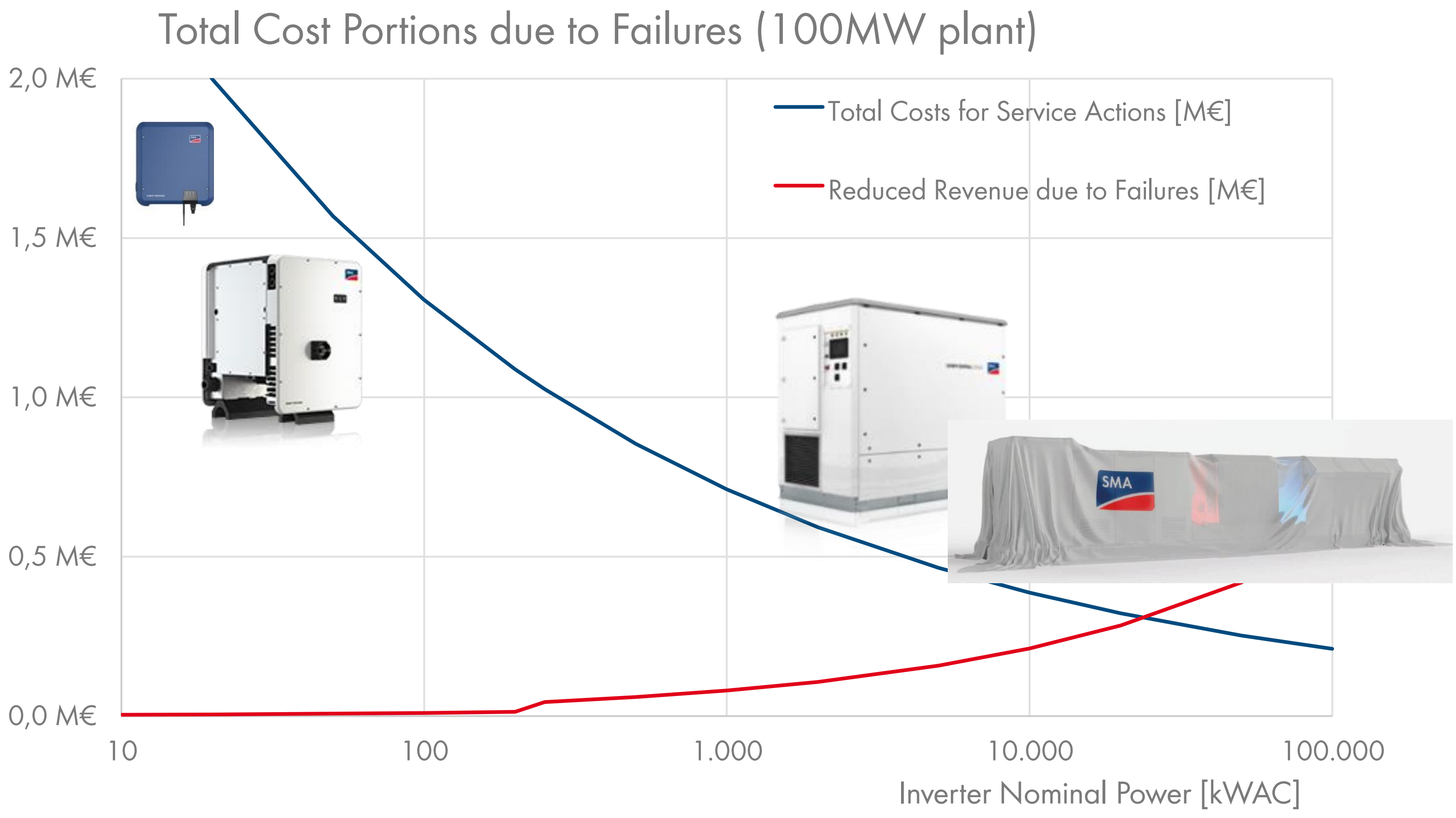
Although Downtime increases with larger inverters, the influence on revenue is much lower than the decreased number of service actions.

Failure Cost Analysis over Inverter Power

Service action costs are dominant compared to lost revenue.

Large inverters serve the lowest possible failure-related costs.

The best inverter is the only one in the installation.



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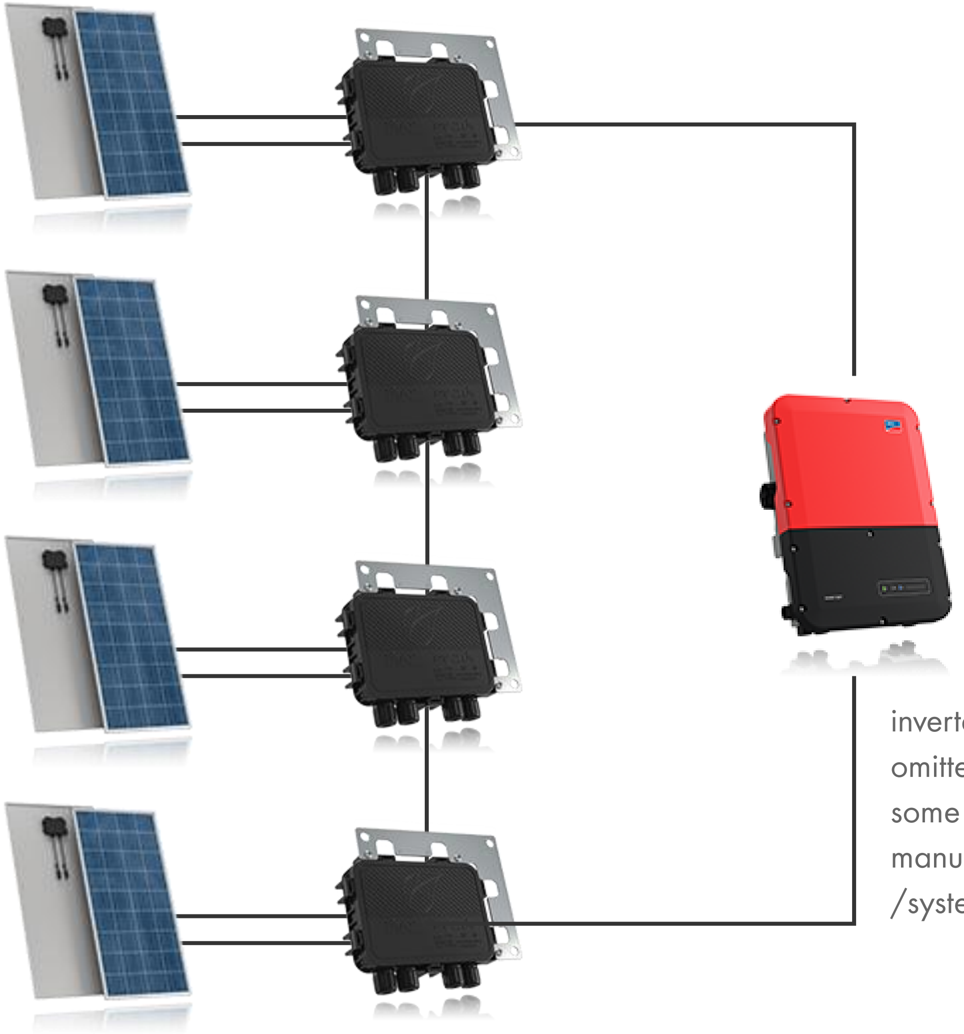
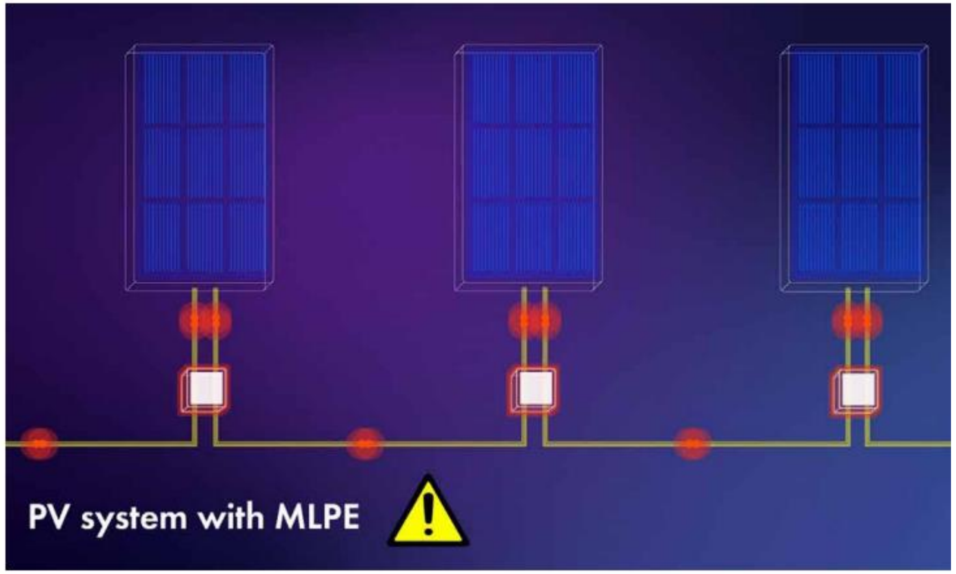
What is MLPE (module level power electronics)



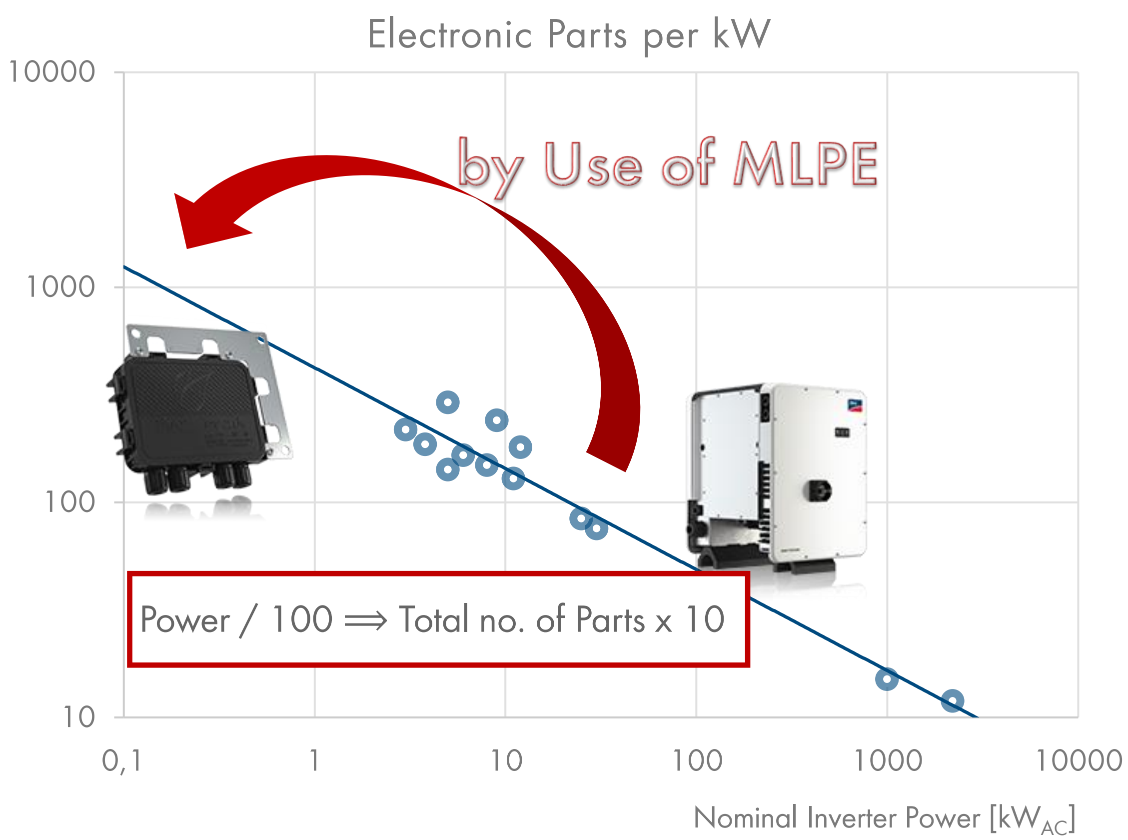
MLPE and its effect on component count

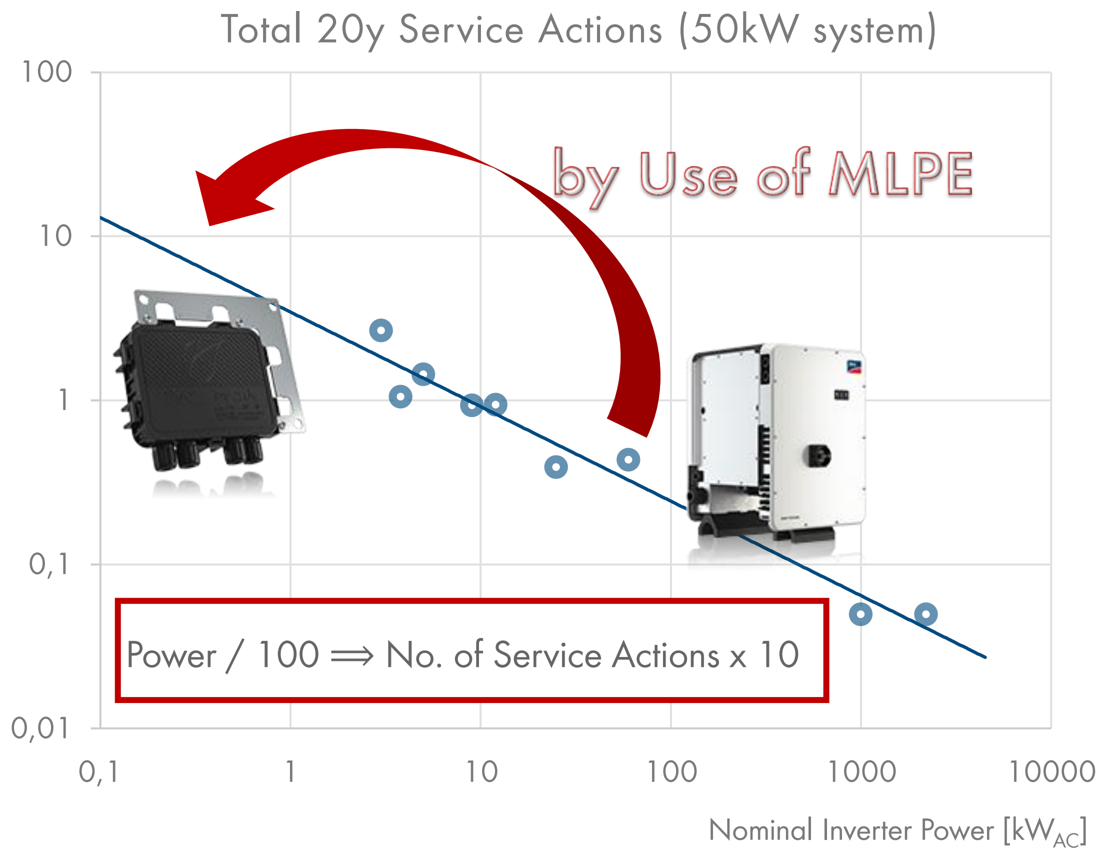


	String Inverter	MLPE
(Additional) electronic devices on the roof	0	200
No. of DC connectors in the PV system	210	610 (~x3)
Total no. of electronic components in the PV system	~2.000	~60.000
no. of elec. components per kWp	40	1.200

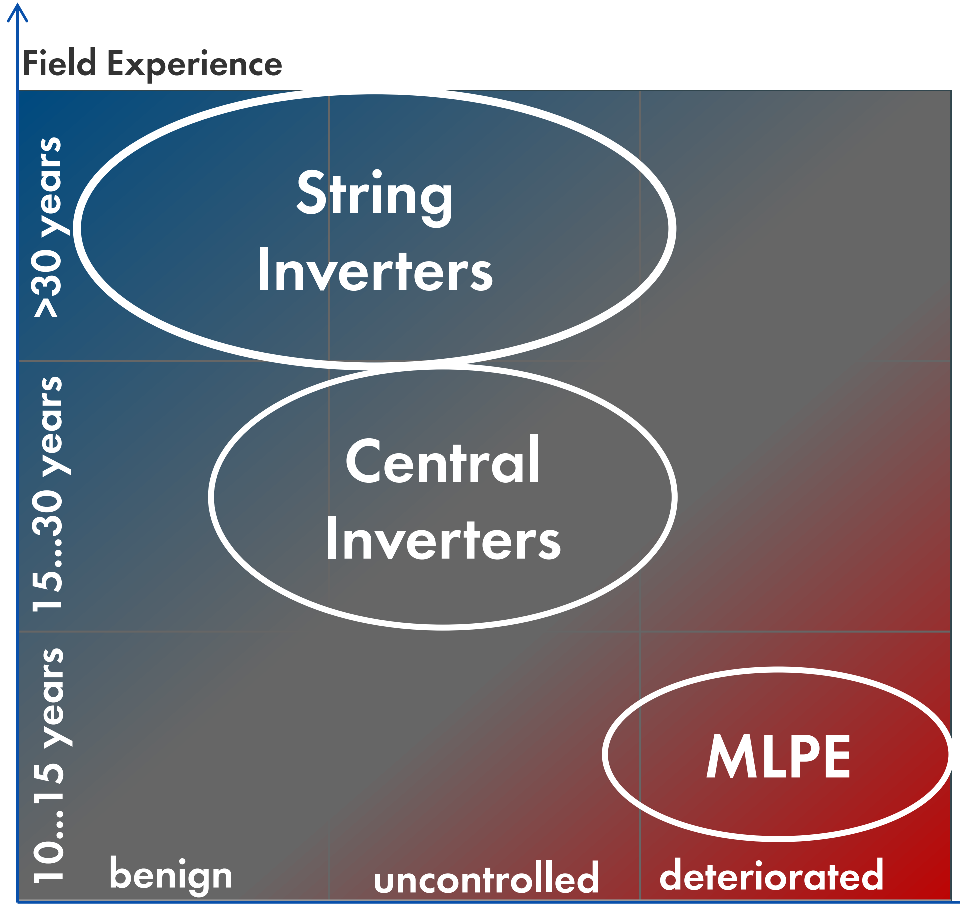
Table: Example calculation for a commercial PV system with Sunny Tripower CORE1 (50 kW_{AC}/60 kW_p – 200 PV modules, each 300 W_p)

Failures as function of Inverter Nominal Power





A View on surrounding Conditions



String Inverters

Field Experience with String Inverters in Europe is up to 35 years. Installations partly indoor, partly outdoor.

Central Inverters

Field Experience with Central Inverters is about 25 years in Europe. Usually outdoor installed.

MLPE

Least Field Experience with Module Level Electronics. Mounting under Modules in most severe ambient conditions

MLPE myths

higher revenue	Myth Busted – overall efficiency loss eats up advances during partial shading[1,2]
higher lifetime	Myth Busted – 30y lifetime is pure marketing. Instead more components lead to more failures[3]
easy installation	Myth Busted – More work to be carried out on the roof, largely reduced accessibility upon failures
cost effectiveness	Myth Busted – 50 to 100€ extra material cost per kWp eats up a full year revenue[4]
Higher safety level	Myth Busted – extra components and specially extra connectors increase risk of fire[5]
reduced planning efforts	Myth plausibel – installers do not need to bother about string plans
higher installer revenue	Myth plausible – higher total price also increases installer profit margin

"All connections provided by the customer are potentially critical"

Fraunhofer ISE and TÜV Rheinland: Guideline on Assessing Fire Risks in Photovoltaic Systems and Developing Safety Concepts for Risk Minimization – June 2018

„They are called optimizers, since they optimize the installers margin"

unkown PhotovoltaikForum user

Fact checks:

1. The Impact of Optimizers for PV-Modules A comparative study – University of Southern Denmark, 2009
2. Effizienzanalyse von dezentraler Photovoltaik Leistungselektronik bei Teilbeschattung, Züricher Hochschule für angewandte Wissenschaften - 2023
3. Life Expectancy of PV Inverters and Optimizers in Residential PV Systems, Bern University of applied science – 2022
4. With current (2024) German feed in tarif and 950kWh/kWp ~73€
5. Fraunhofer ISE and TÜV Rheinland: Guideline on Assessing Fire Risks in Photovoltaic Systems and Developing Safety Concepts for Risk Minimization – June 2018

Conclusion

Design For Reliability

Accelerated Ageing is the way to reliable PV Systems.

All members of the value chain need to participate and support the approach.

One Inverter per Installation

Parts are reduced effectively by large inverters.

SMA Central Inverters serve the highest power at lowest overall complexity.

Reduce Complexity

A large leverage to increase reliability is the reduction of parts.

Use simple system structures.

Module Level Power Electronics

By the use of MLPE, the number of components in the system is drastically increased.

All solutions involving MLPE lead to less reliable, cost intensive systems.

Thank you

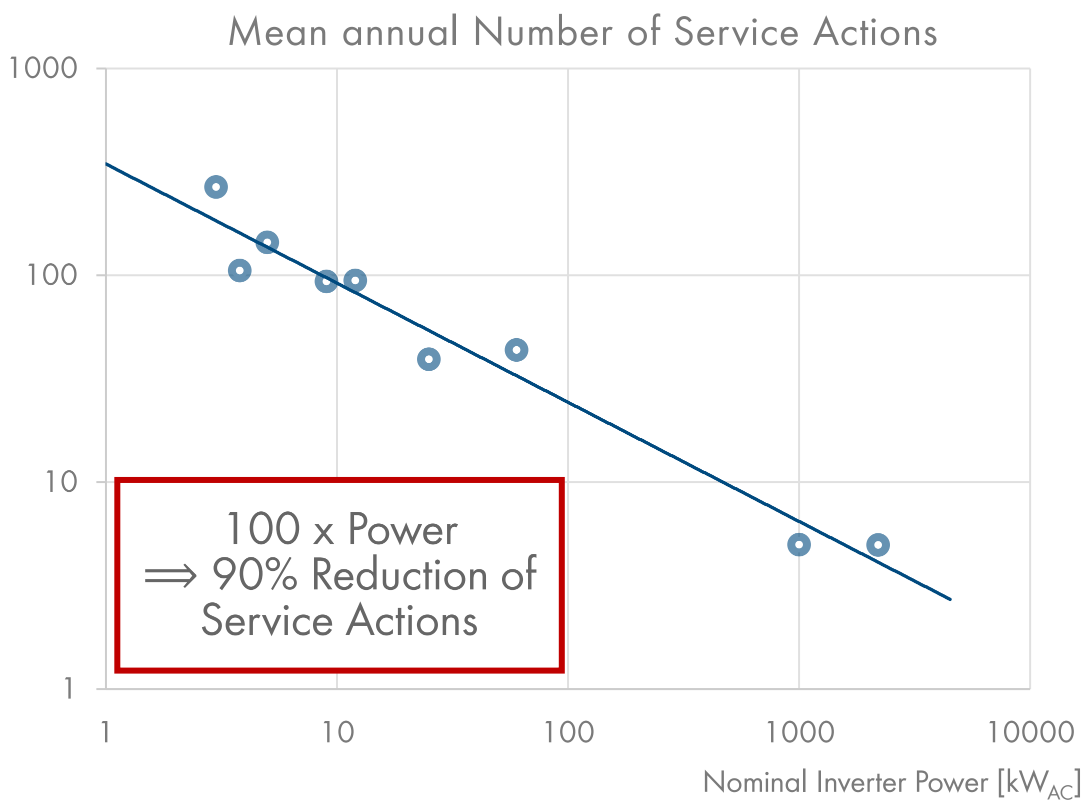
SMA Solar Technology AG

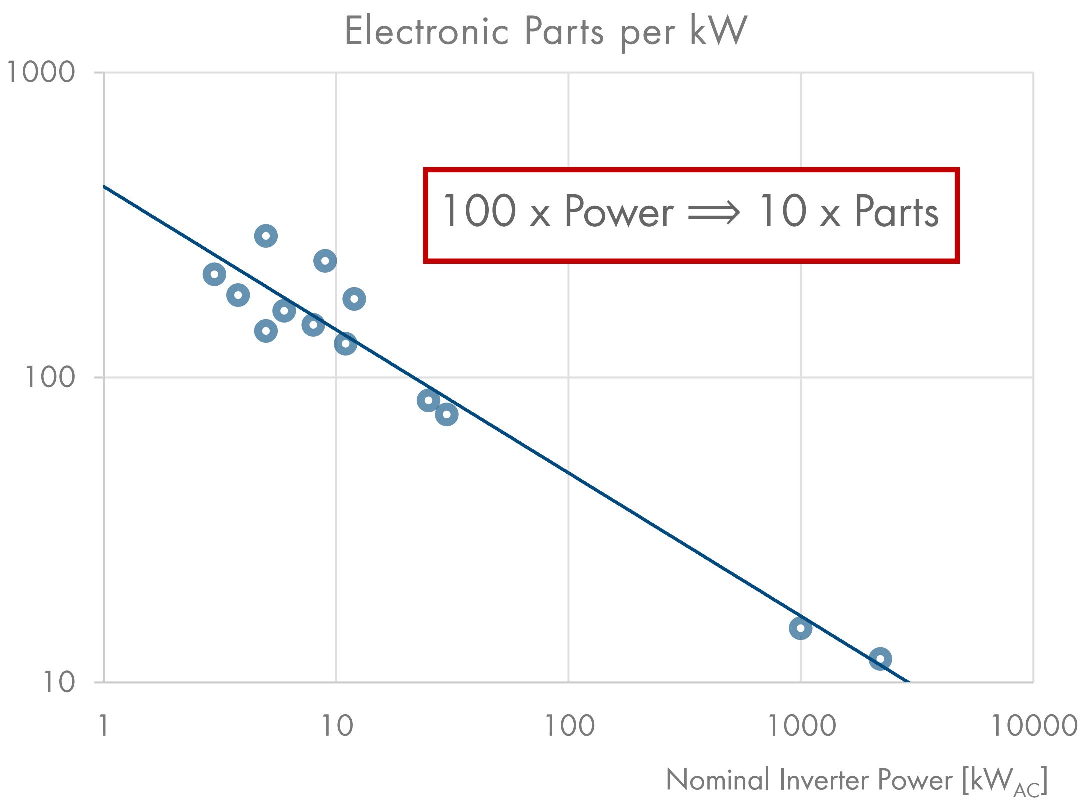
Sonnenallee 1
34266 Niestetal, Germany

Tel. +49 561 9522 0
Fax +49 561 9522 100

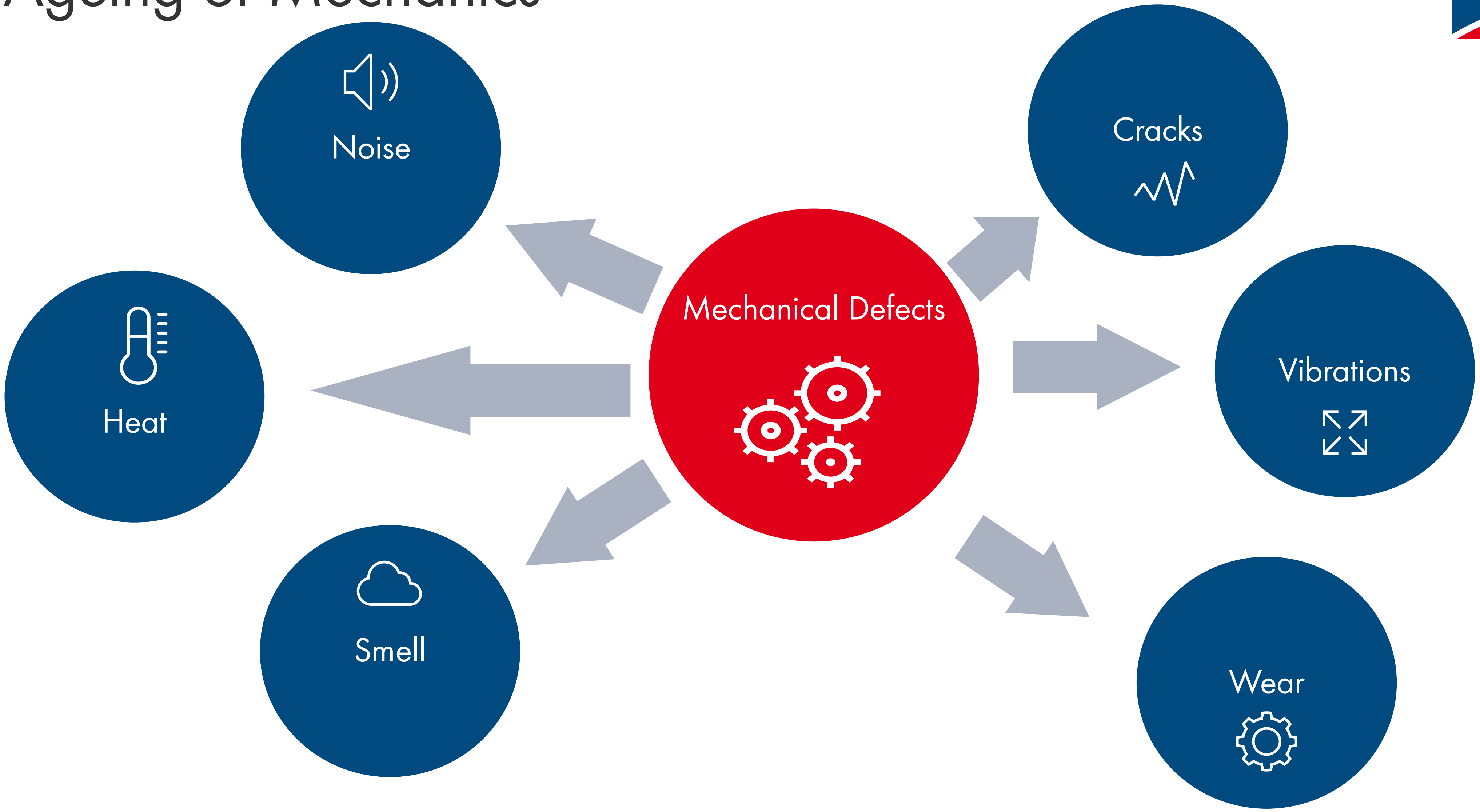
www.SMA.de
info@SMA.de

Failures as function of Inverter Nominal Power

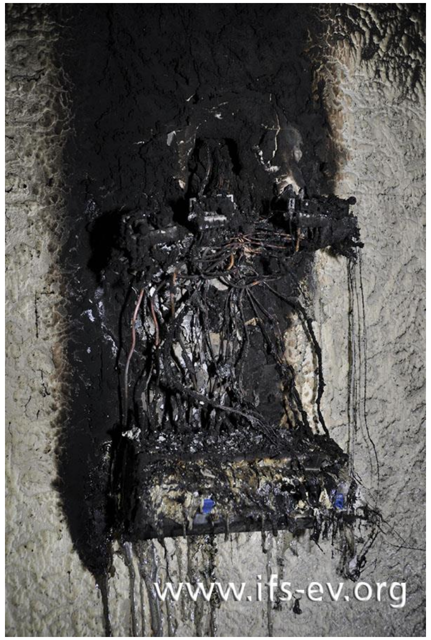




Ageing of Mechanics



Aging of Electronics



System Design Aspects

SMA

Reduce To The Max

LCOE Analysis

Thank you

SMA Solar Technology AG

Sonnenallee 1
34266 Niestetal, Germany

Tel. +49 561 9522 0
Fax +49 561 9522 100

www.SMA.de
info@SMA.de

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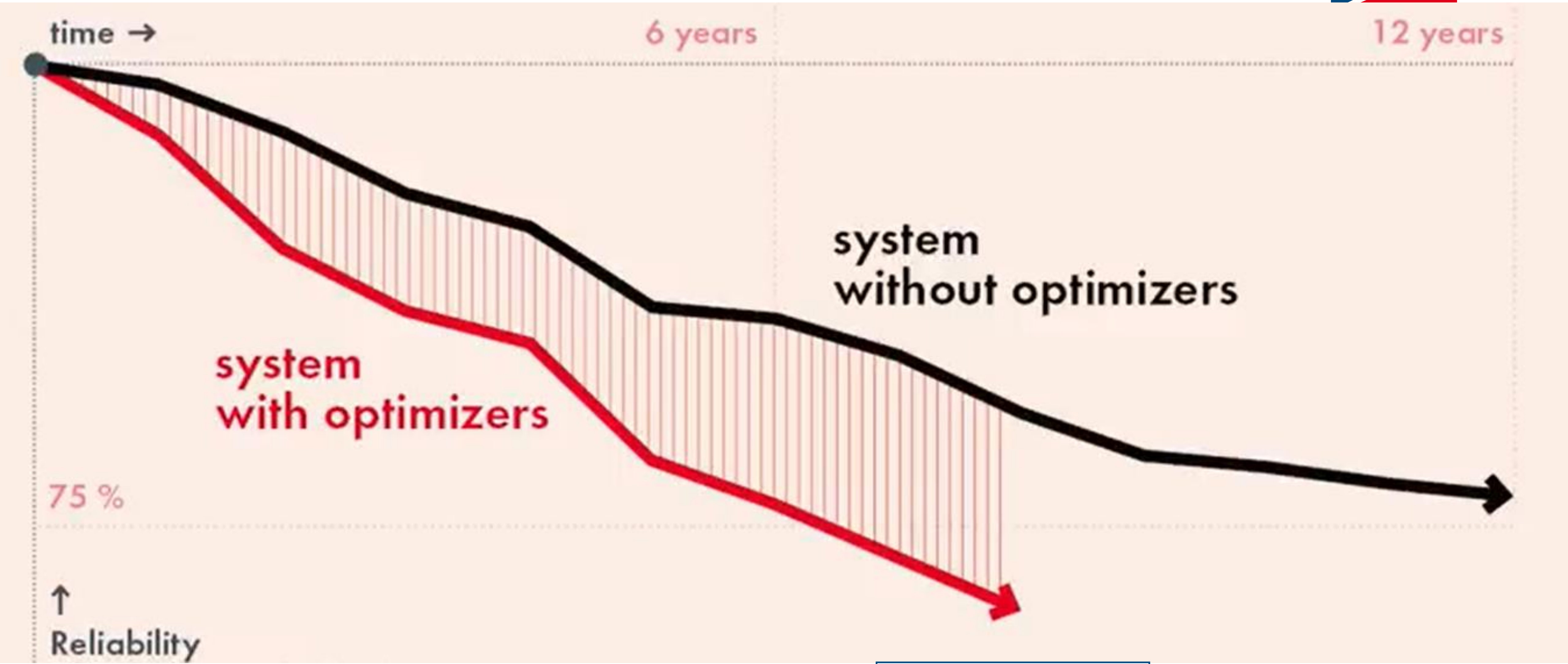

BFH Study

Quality Without Compromise

Test Centers


SMA
Bettenhäuser Straße
Ludwig-Raabe-Straße
Egon-Höhmann-Straße
LIDL
Grünstraße
Hannoversche Straße
KIK
EDEKA
ALDI
JET
SMA
Sonnenallee
Willi-Apel-Platz
Mündener Straße
Dresdener Straße
Göttinger Straße
Osterholzstraße
Miramstraße
Sandershäuser Straße
Salzmannshausen
Salzmannstraße
Holländische Straße
63
Parkdeck
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64
67
93
60
61
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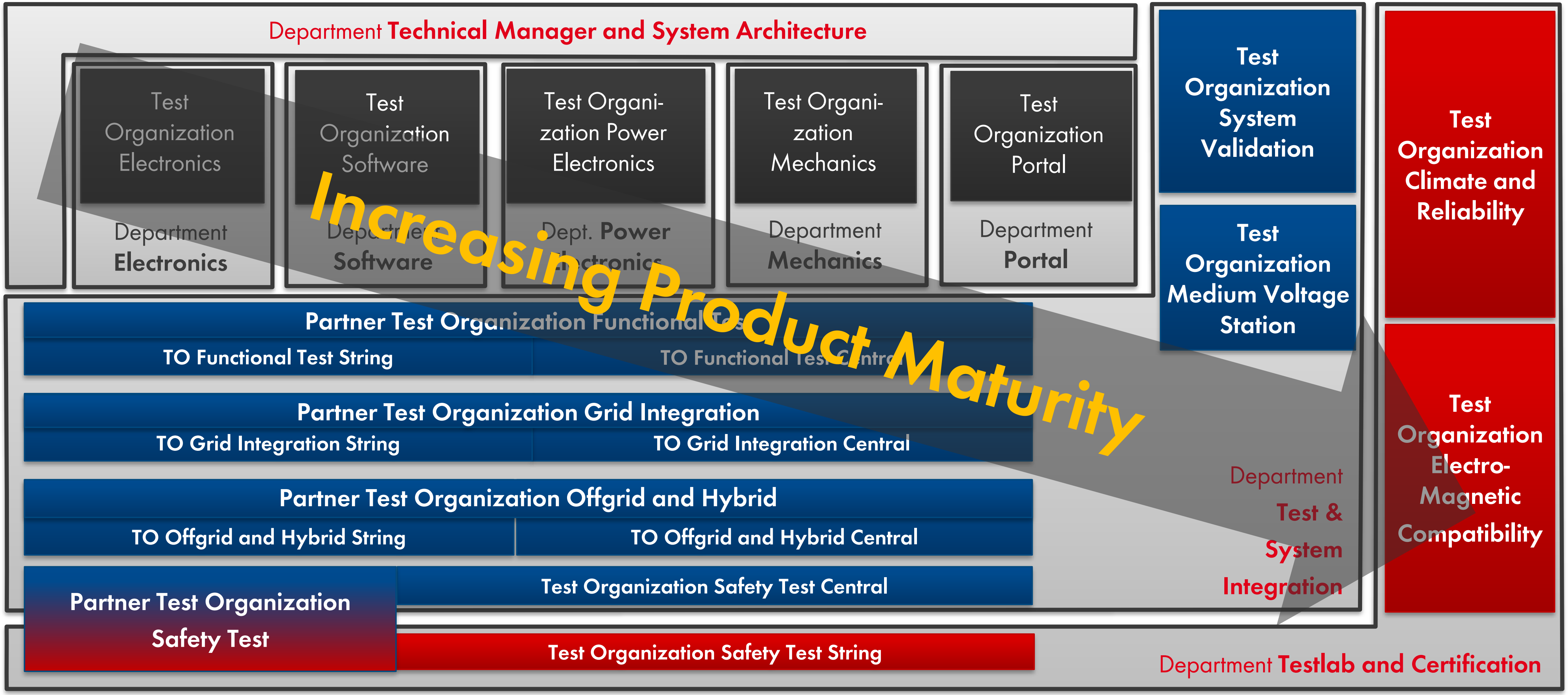
28

Test Organization Overview

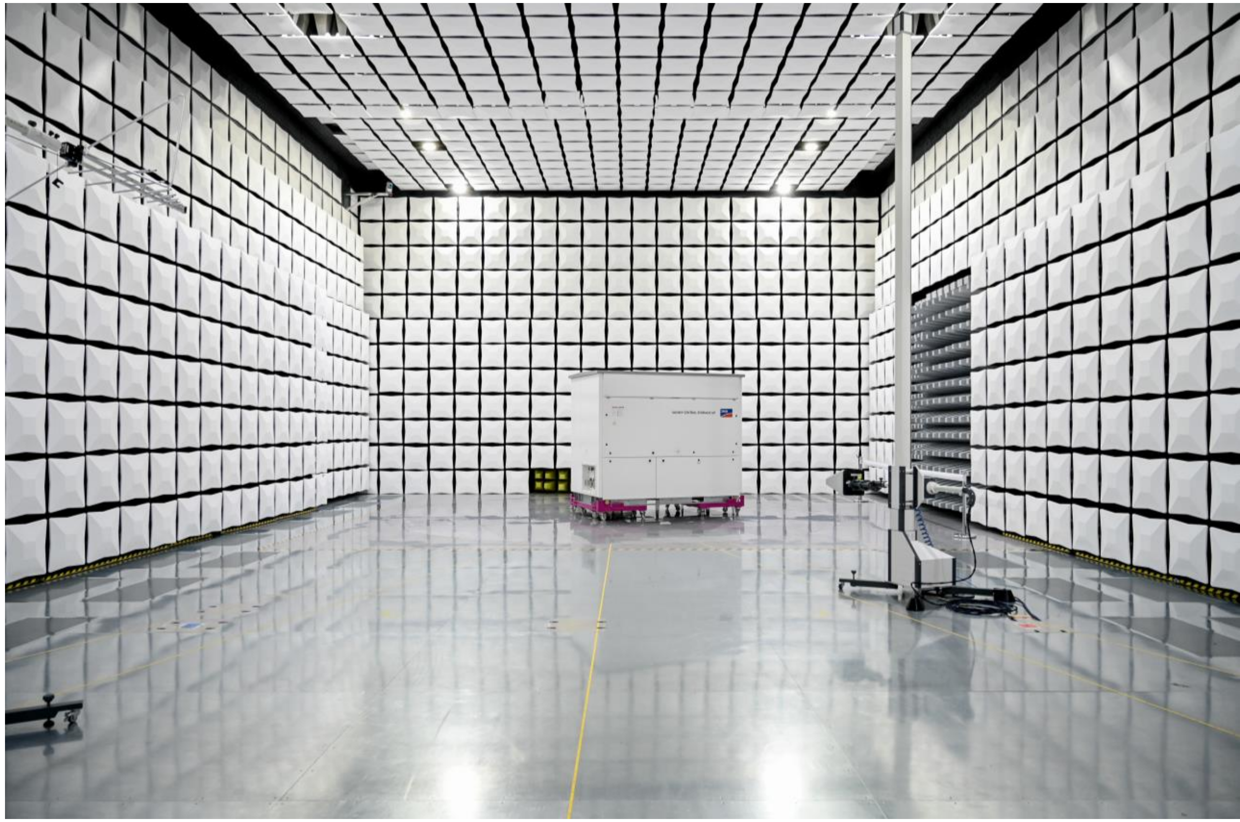


Test Organization Offgrid and Hybrid Central

- DUT: device under test
- REAL HARDWARE (PPM, SC or SCS, BATT)

Test Organziation Electromagnetic Compatibility

- 740 square meter
- Devices up to 30 tons and up to 200 kW of waste heat
- Electrical outputs up to 5 MW
- Prevent external electromagnetic waves to damage SMA devices
- Prevent SMA devices to cause interference to external environment



Test Organization Climate and Reliability

- Endurance Warm
  - 4,000h at 50°C ambient, constant operation, intermittent restarts
  - Comparison to IEC 62093: 2,000h

Ageing effects due to high temperature, migration and diffusion effects

- Power Cycling Cold
  - 2,000h at -23°C ambient, intermittent operation
  - Comparison to IEC 62093: ~500h

Ageing effects due to freezing, water, drying of components, hardening of greases and plastics

- Humidity Cycling
  - 42 days of operation under extreme temperature slopes and high humidity
- Comparison to IEC 62093: 20 days

Ageing effects due to accumulation of moisture on PCBAs and in plastics, electrochemical and condensation effects

- Thermal Shock
  - 1,275 cycles from -30°C to +90°C passive
  - Comparison to IEC 62093: not performed

Ageing effects of solder joints and other material interfaces

No Failure Occurs Twice

D7 Action Process

D7 Measures Process

CAPA Process: Root Cause (D4) Established for a Certain Failure

→ **Continuation of CAPA Process: D5 and D6 for Existing Products**

Selection of Appropriate Preventive Action by 8D Team

Measure	Considered in Development Process
Knowledge Database	Layout Phase
Design Rules	Lead Engineer (FGM) in Design Phase
Test Specifications	Test Organization Manger in Qualification Phase
Specification Template	Responsible Engineer during Sourcing
Supplier Audit Checklist	Quality Manger during Sourcing
FMEA Template	FMEA Moderator in Design or Process FMEA

> Knowledge Database and Design Rules are preferred D7 measures.