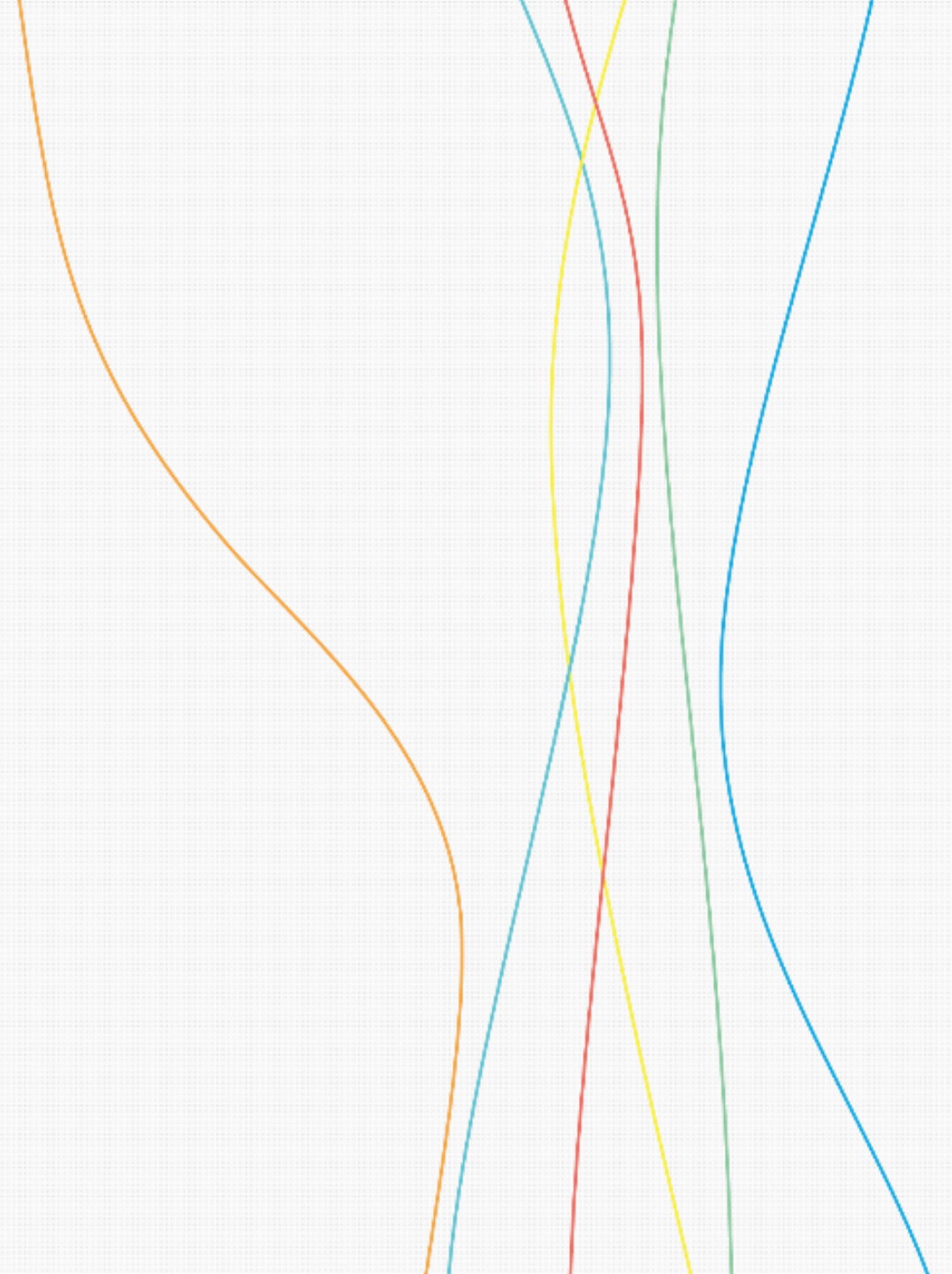


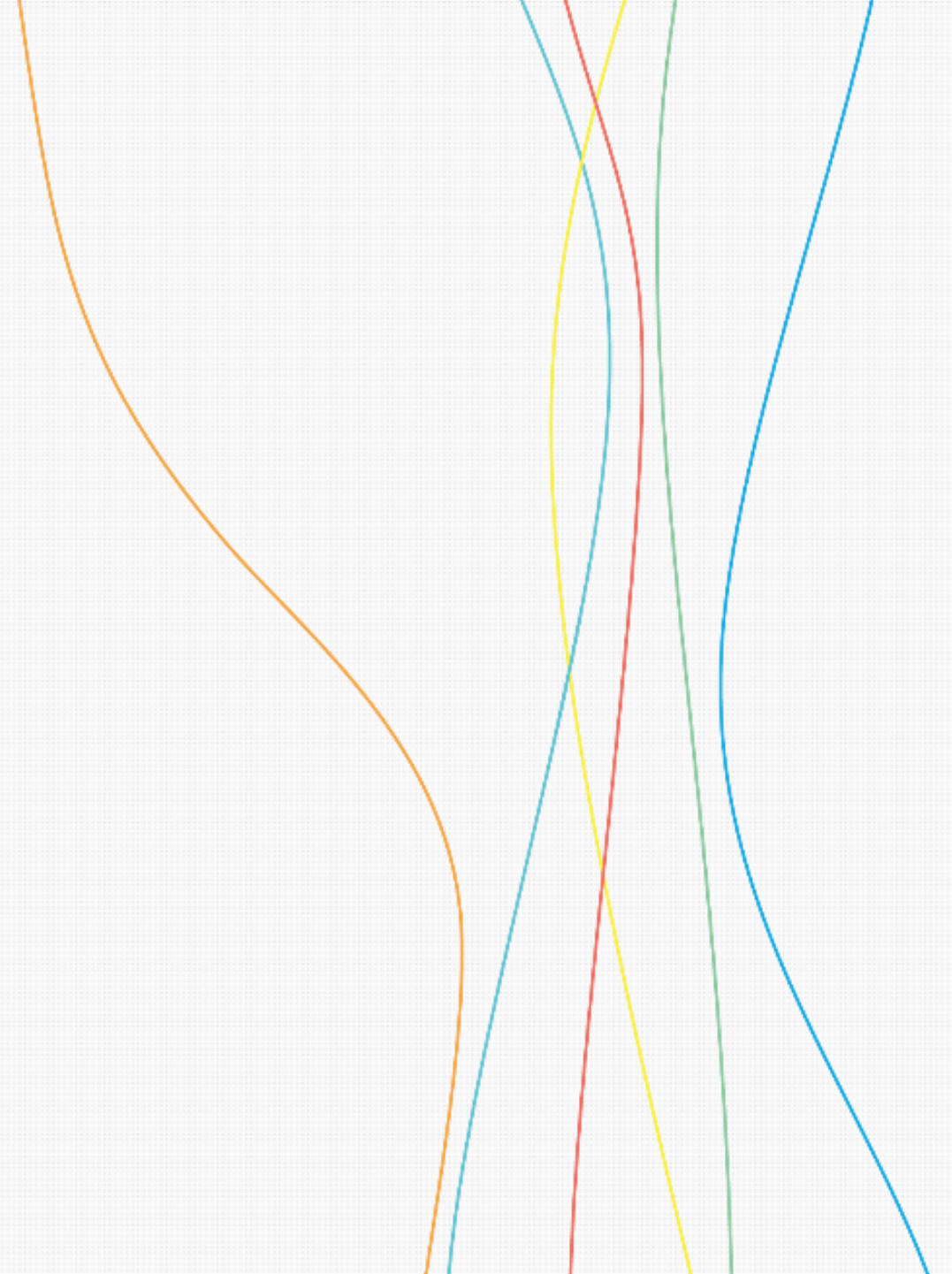


Smart IV Curve Diagnosis





Panel Faults is Threatening Your Solar Investment



Panel faults significantly increase PV plant investment risks

TUV:

An investigation indicates among 12GW plants, 30% (3.6GW) has severe defects, and 50% (1.8GW) of them results from panels

Mannheimer Insurance AG:

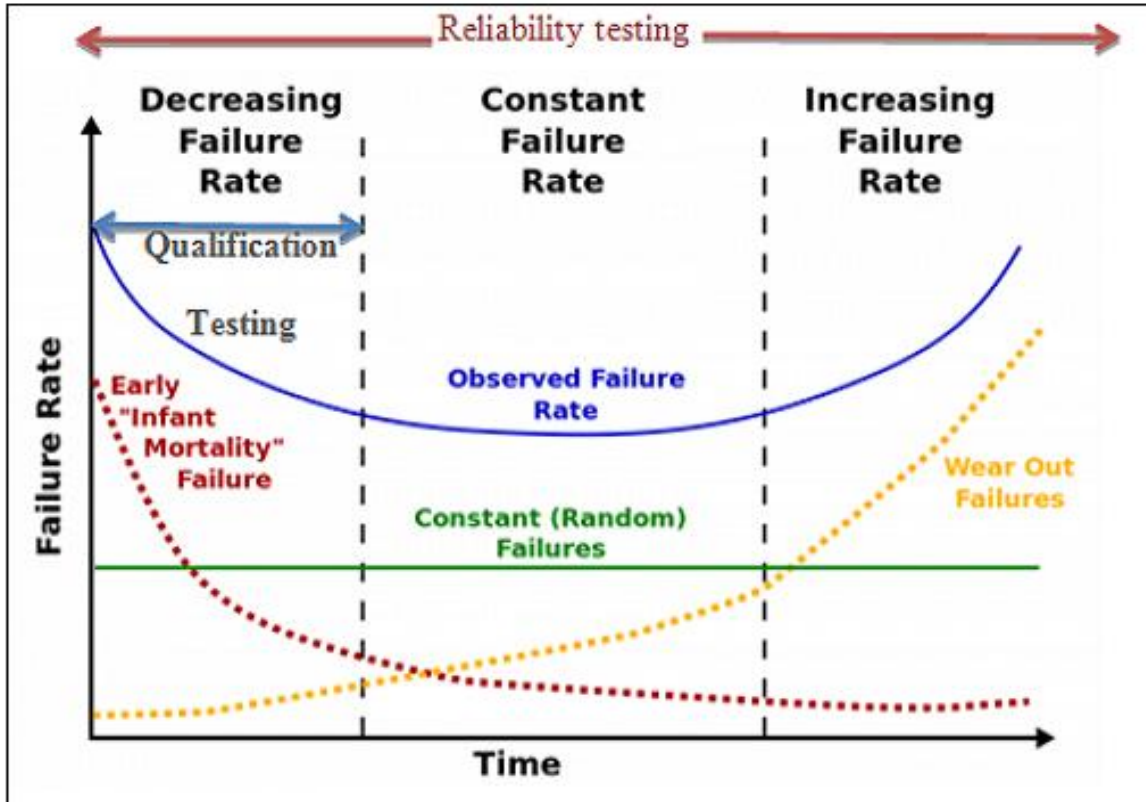
10% of operating solar plants have panel faults

The highest technical risk involved in PV investment is early-life failure & long-term failure of panels.

Rating	Investment Risk	Technical Risk	Quality	Manageable by investors and buyers?
●	High	Early-life product failure or overt safety hazard	Poor	No
●	Medium-high	Long-term product failure or significant under-performance	Below average	Complex
●	Medium	Moderate under-performance	Average	Manageable
●	Medium-low	Limited under-performance	Above average	Easy to manage
●	Low	None	Excellent	Little or no management necessary

Source: Connecting PV Module Quality to Field Degradation, **SOLARBUYER**

Failure rate of solar panels during entire lifespan

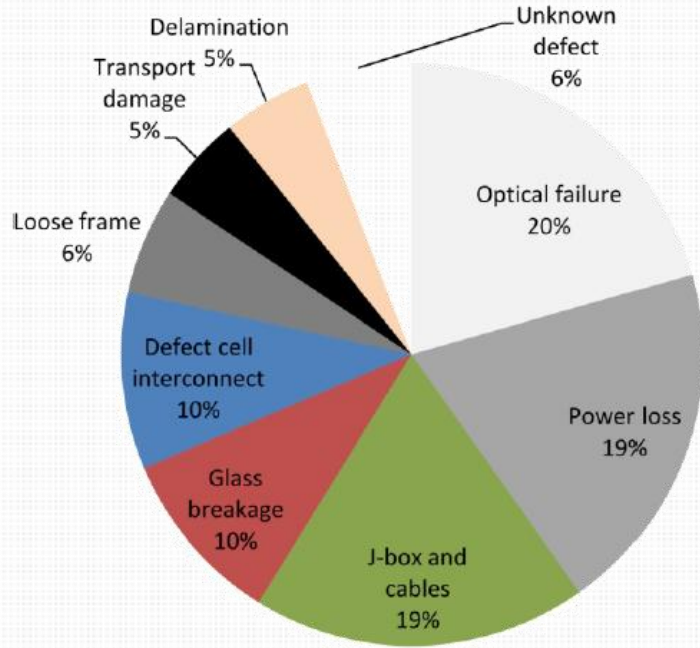


Early-life failure is mainly caused by quality problem and leads to heavily power output reduction

Panels in mid-term operation are relatively stable and remains low failure rate

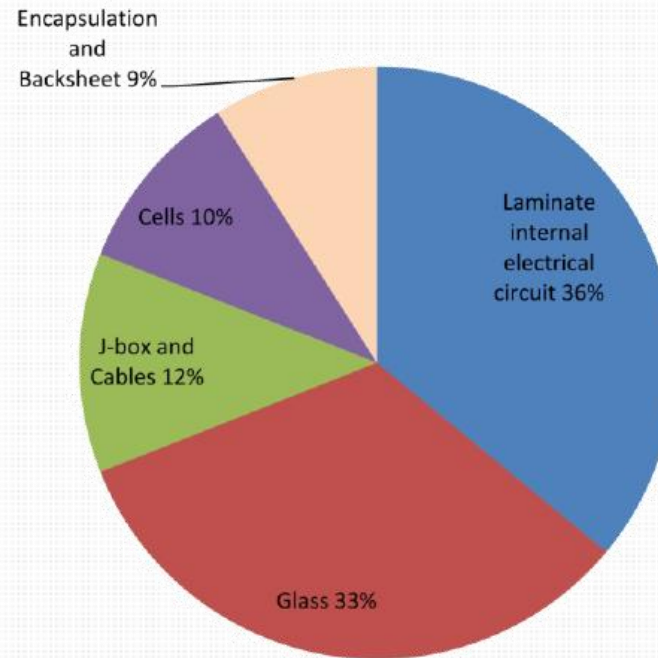
Failure rate of solar panels during lifespan: high at initial term, stable and relatively low during mid-term operation and significantly rising up at terminal phase

Early life, mid-term and long-term panel failure types



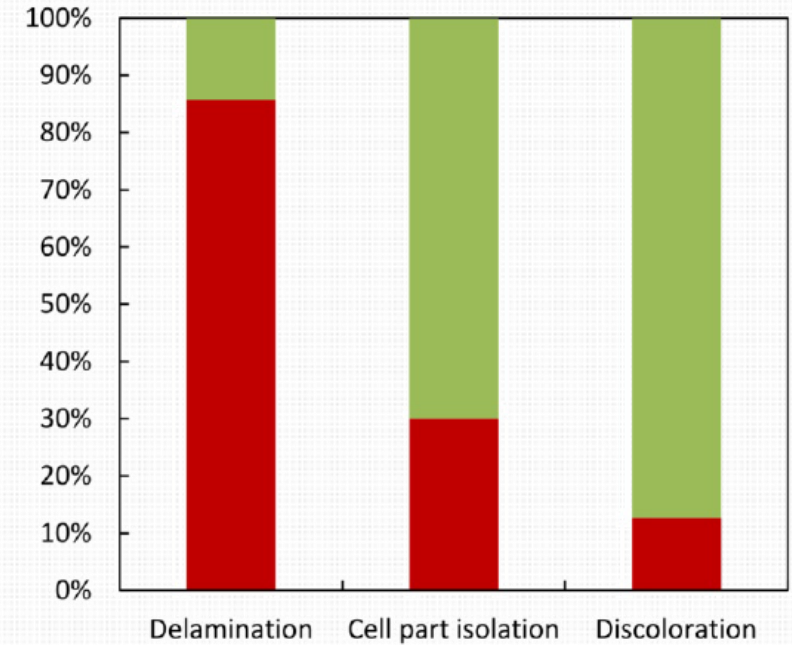
Early-life failure typical fault types and percentage

Source : A.Richter, Schadensbilder nach Wareneingang und im Reklamationsfall, 8. Workshop 'Photovoltaik-Modultechnik', 24/25. November 2011, TUV Rheinland, Koln



Mid-term solar module failure typical fault types and percentage

Source : D.DeGraaff, R.Lacerda, Z.Campeau, Degradation Mechanisms in Si Module Technologies Observed in the Field; Their Analysis and Statistics, Presentation at PV Module Reliability Workshop, NREL, Denver, Golden, USA (2011)



Long-term solar module failure typical fault types and percentage

Source: K.Schulze, et.al, Proceedings of 28. Symposium Photovoltaische Solarenergie, (OTTI, Staffelstein, Germany, 2012)

Typical panel faults



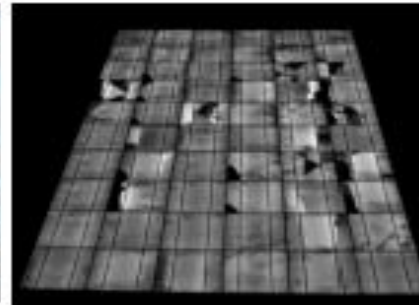
Shattered glass



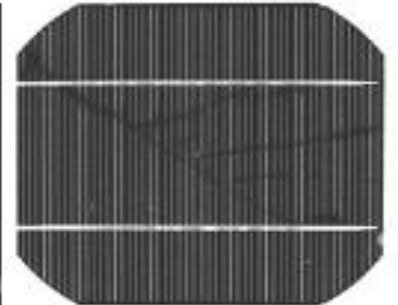
EVA discoloration



EVA delamination



Cell cracks



Snail trails



Metal corrosion



Backsheet chalking

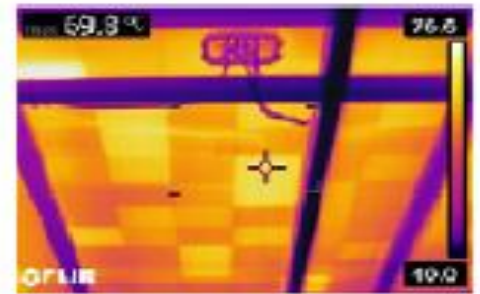


Pre stress



Stress 1

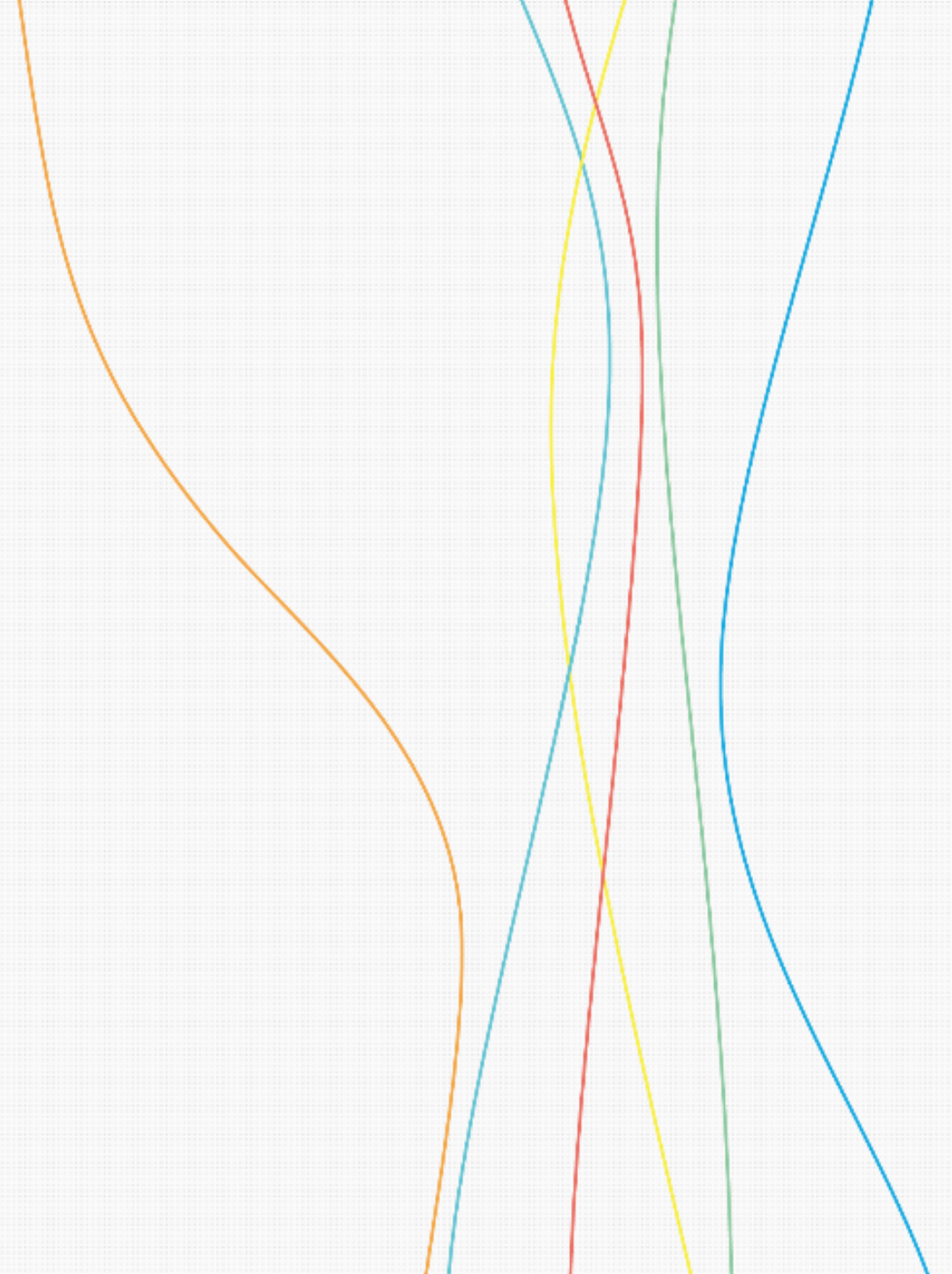
Potential induced degradation



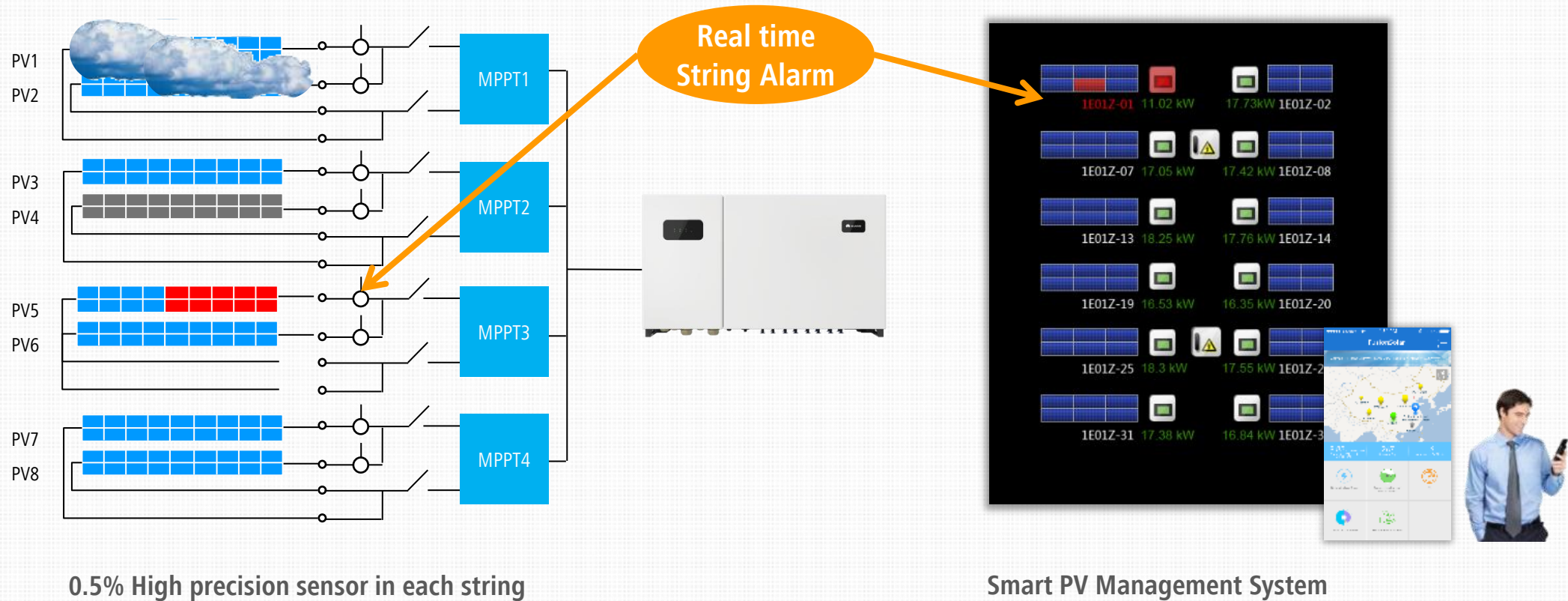
Hot spots



Smart IV Curve Diagnosis



Quick fault discovery through high precision string management

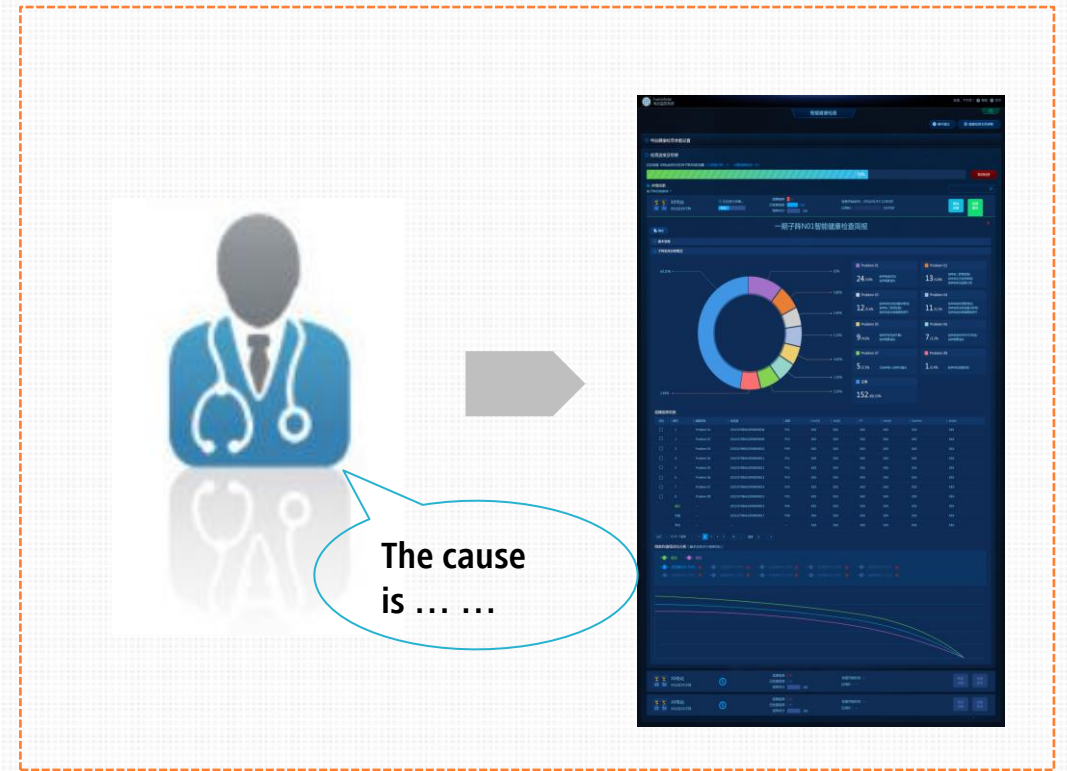


How smart diagnosis different from String-level management?

String-level management



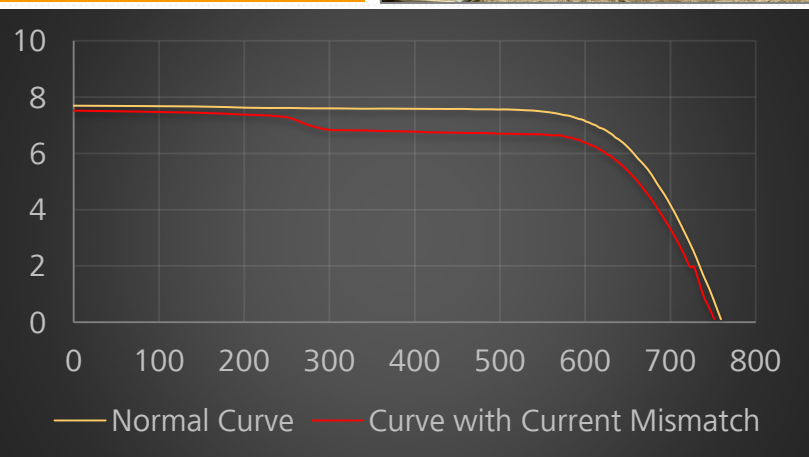
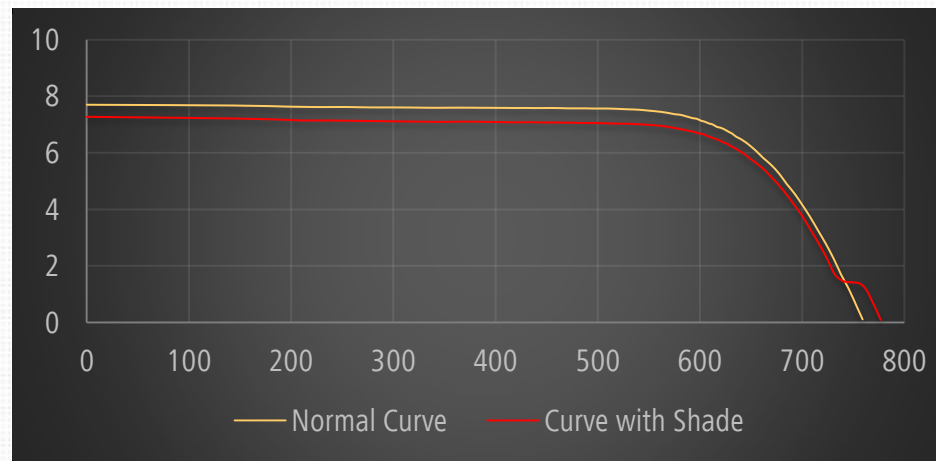
New feature: Smart Diagnosis



Smart IV Curve Diagnosis Principle

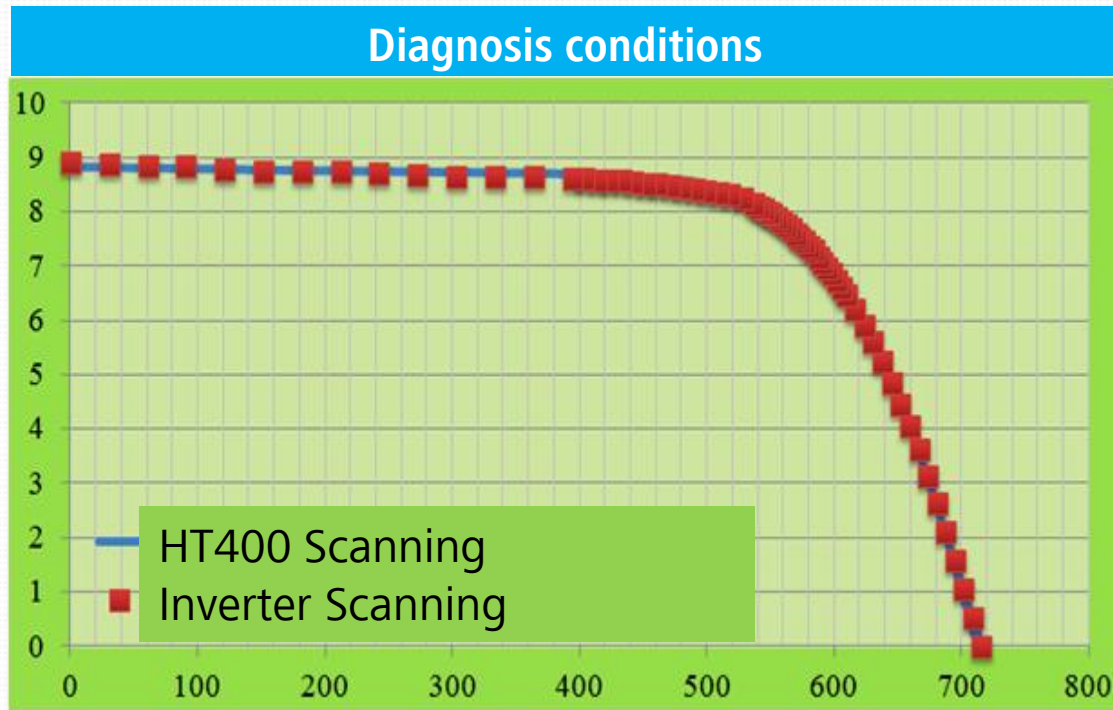
Different panel failure would have different IV curve patterns, causes of failure could be determined when an analyzed specific IV curve matched with an existing pattern.

Strings with shade on panels

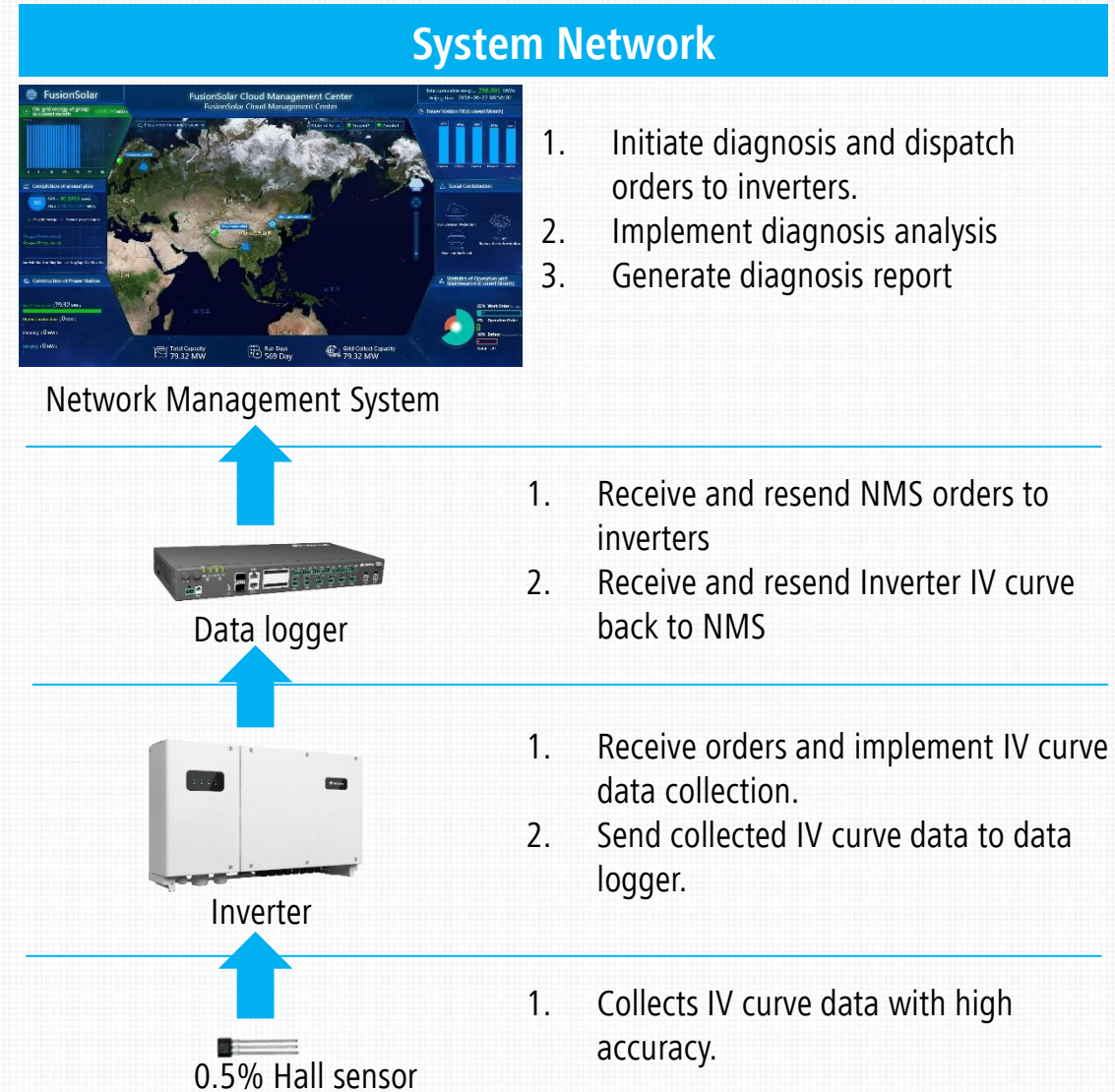


Strings with current mismatch caused by using a mixture of modules or dust, PID,

Smart IV curve diagnosis conditions and system network



For a better IV curve diagnosis accuracy, it is recommended to initiate diagnosis when solar irradiation larger than $500\text{W}/\text{m}^2$



Industrial IV Curve Test Instrument vs. Smart IV Curve Diagnosis

Items	IV Instrument	Huawei IV Diagnosis	Values Proposition
Times	< 5s	< 1s	5s may lead to string overheating and affecting test result
Scan Resolution	101 Points	128 Points	Achieving industry standard
Scan Accuracy	Voltage: $\leq 1\%$ accuracy Current: $\leq 1\%$ accuracy	Voltage: $\leq 0.5\%$ accuracy Current: $\leq 0.5\%$ accuracy	Achieving industry standard
Convenience	Require disconnecting strings onsite before test	No onsite job.	Much more easier
Scan consistency	One string per time	One Array per time with strings scanned same time.	Better to find the string difference when test with consistency
Scan Volume	<1~5% Sampling, purposeless, hard to detect problem	Full string scanning, detect potential problem in each string	Reduce Onsite O&M Cost hugely.
Ease of Use	Need 2 experts onsite operation, with special professional device	Remote online one click	Reduce onsite O&M work load
Data Analysis	Human involved afterwards analysis and report writing	Auto analysis with report generated in 4-6 mins.	Less reliance on experts, a easier way to achieve professional O&M
Power Loss	10MW with 1%~5%, power loss over 100kWh, around 38,000 Euros per time if choose full string test	≈ 0 kWh power loss, unlimited time	Almost no power loss on Huawei solution

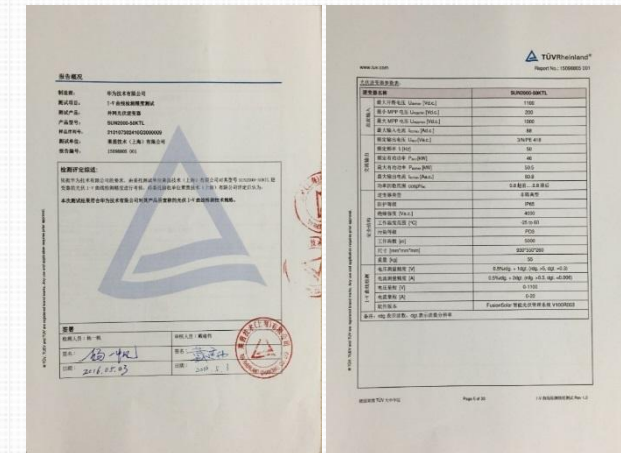
Failure types can be detected by Smart Diagnosis

Smart diagnosis can accurately detect total 21 panel failure types, 17 categories.

Open circuit of string
Current mismatch in string
Abnormal module current output (shadow, Glass breakage, hidden cracks)
Extreme-low current output by module/cell (panel cover up / cell damage)
Diode break-over fault (diode short circuit / Bracing breakage)
Low string voltage
String with minor current mismatch
Panel with hidden cell cracks
String with high resistance
Low string short circuit current
High decay speed of string
No string connected
Incorrect string configuration
Invalid string
Invalid scanning
No string output
Risk of PID

TUV Verification

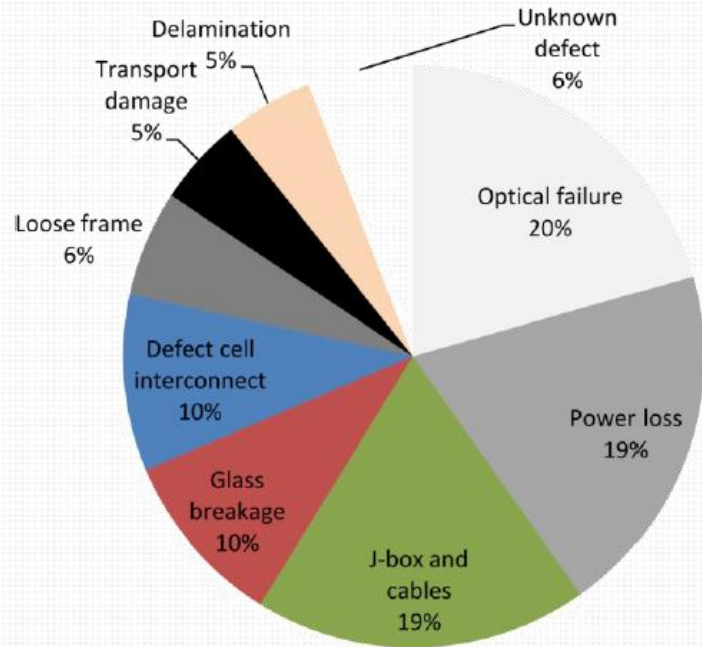
0.5% Sensor Accuracy



14 string related faults have all been verified by TUV



Early life failure Type & IV Curve Smart Diagnosis Accuracy

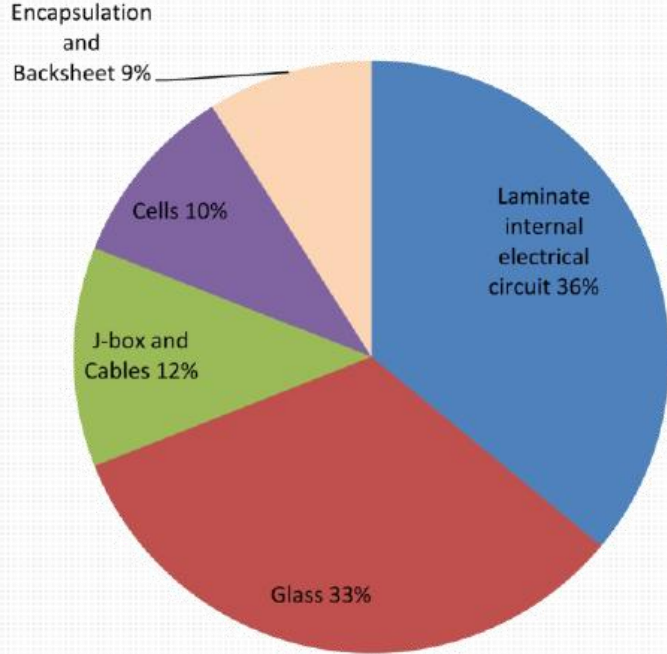


Early-life failure typical fault types and percentage

Source : A.Richter, Schadensbilder nach Wareneingang und im Reklamationsfall, 8. Workshop 'Photovoltaik-Modultechnik', 24/25. November 2011, TUV Rheinland, Köln

Fault Type	%	IV Curve Diagnosis	Description
Optical Failure	20%	0	<ul style="list-style-type: none"> ◆ IV Curve with ultra low Isc ◆ IV Curve with current mismatch
Power loss	19%	0	IV Curve with obvious reduction on maximum power point.
J-Box and Cables	19%	0	Diode short circuit within wiring box could be detected.
Glass Breakage	10%	0	
defect Cell Interconnect	10%	0/X	<ul style="list-style-type: none"> ◆ defective cell interconnection could be detected. ◆ Minor welding problem or bad contact may not be detected in IV curve
Loss Frame	6%	?	Specific IV Curve feature or characteristics not confirmed.
Transport Damage	5%	X	Hidden cracks in modules could hardly be detected with current IV Curve resolution
Delamination	5%	0	<ul style="list-style-type: none"> ◆ IV Curve with ultra low Isc ◆ IV Curve with current mismatch ◆ Abnormal cell output

Mid-term module failure Type & IV Curve Smart Diagnosis Accuracy

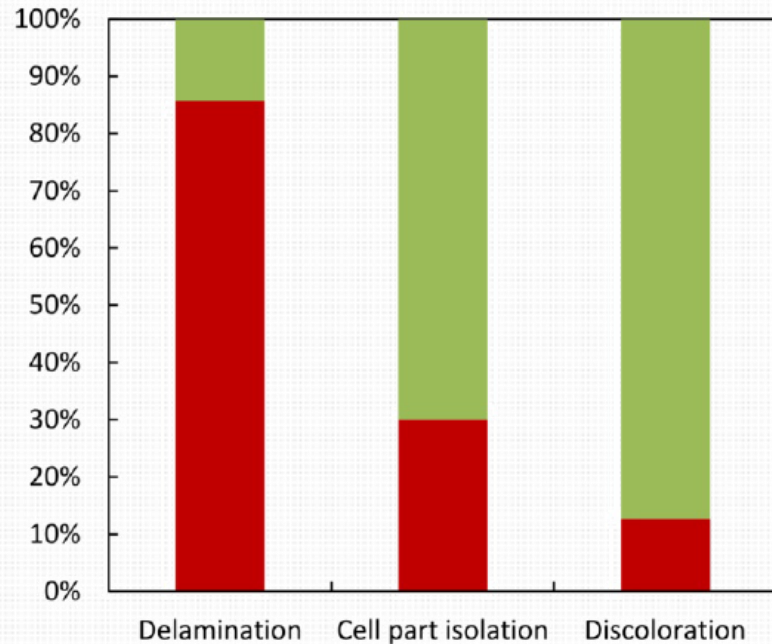


Mid-term solar module failure typical fault types and percentage

Source : D.DeGraaff, R.Lacerda, Z.Campeau, Degradation Mechanisms in Si Module Technologies Observed in the Field; Their Analysis and Statistics, Presentation at PV Module Reliability Workshop, NREL, Denver, Golden, USA (2011)

Fault types	%	IV Curve Diagnosis	Description
defect Cell Interconnect	36%	o/x	<ul style="list-style-type: none"> ◆ defective cell interconnection could be detected. ◆ Cell interconnection corrosion could be detected(from abnormal Rs) ◆ Minor welding problem or bad contact may not be detected in IV curve
Glass Breakage	33%	o	Glass breakage could be detected.
J-Box and Cables	12%	o	Diode short circuit within wiring box could be detected.
Cells	10%	o/x	<ul style="list-style-type: none"> ◆ Serious cell abnormal could be detected. ◆ For minor hidden cracks and hot spot, IV curve may not be able to detect due to insufficient resolution.
Encapsulation and Backsheet	9%	o/x	To serious encapsulation problems: <ul style="list-style-type: none"> ◆ Isc of IV Curve will be decreased ◆ IV Curve will occur current mismatch Backsheet failure will lead to panel power decay.

Long-term failure & IV Curve Smart Diagnosis Accuracy



Long-term solar module failure typical fault types and percentage

数据来源：K.Schulze,et.al, Proceedings of 28. Symposium Photovoltaische Solarenergie, (OTTI, Staffelstein, Germany, 2012)

Fault Type	%	IV Curve Diagnosis Accuracy	Description
Delamination	80%	0	<ul style="list-style-type: none"> ◆ Isc of IV Curve will be decreased ◆ IV Curve will occur current mismatch ◆ Abnormal cell output
Cell Part Isolation	10%	0	<ul style="list-style-type: none"> ◆ Abnormal cell output
Discoloration	10%	0	<ul style="list-style-type: none"> ◆ Isc of IV Curve will be decreased ◆ IV Curve will occur current mismatch

Smart IV Curve Diagnosis, To precisely manage your utility-scale PV plant

**Faster &
Automatic
Diagnosis**

- Annual PV plant health check
- Single unit diagnosis

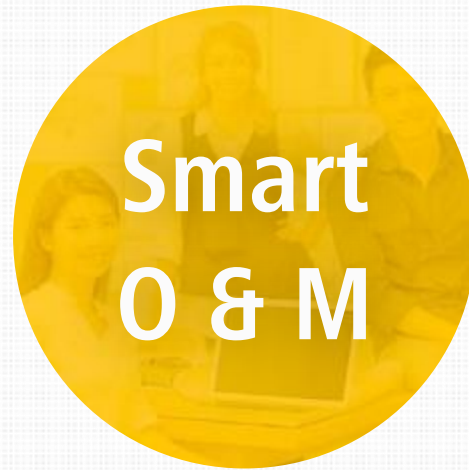
**Lower
O&M Cost**

- No onsite sampling diagnosis
- Inspection with purpose, reducing labor cost

**Decision
Making
Supports**

- Future procurement suggestion
- O&M Strategy suggestion

Always Available for Highest Yields



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