tenKsolar®

fundamentally
better
solar

tenKsolar's Cell-to-Grid Redundant PV System delivers High System Availability

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tenKsolar generates 40% more energy per Watt with standard PV materials

- More Energy Per Sq. Ft.
- More Energy per Installed KW
- Faster, More Flexible Installs
- Very Light Weight
- High System Availability
- Built In Safety

Performance of typical 250 KW Solar PV system in New Jersey

	tenKsolar	Conventional
Lifetime Energy Generated	10,400,000 kwh	7,800,000 kwh
Typical Weight	<4.5 lbs / ft^2	<6.4 lbs / ft^2
Roof Penetrations	None	Typical
Arc Fault / Fire Risk	None	Yes

tenKsolar® fundamentally better solar

Cell to Grid Redundant PV Array Delivers High System Availability

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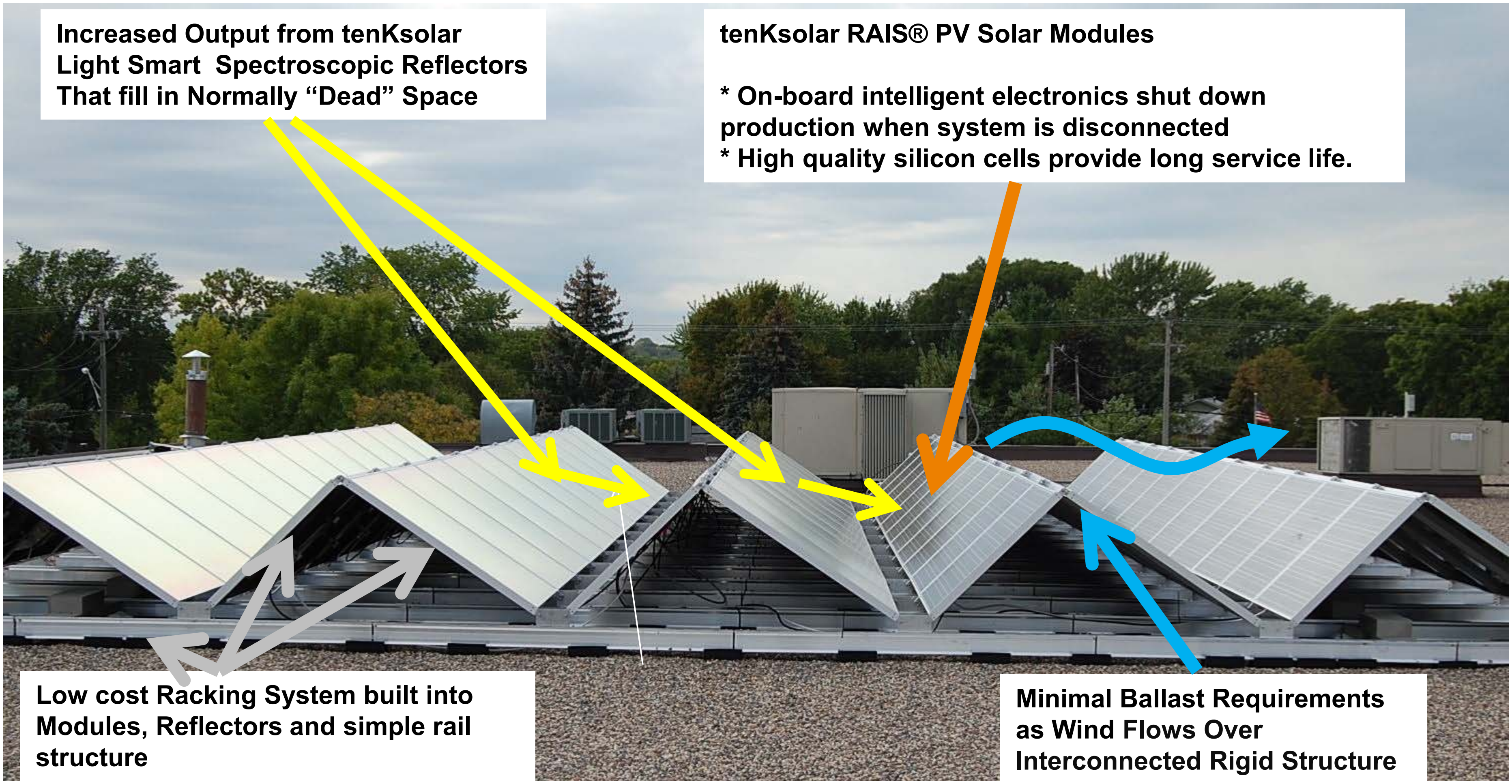
The RAIS® WAVE was designed as a complete system.



Design Challenge

- The availability of today's communications infrastructure were made possible by redundant systems
  - Data Processing
  - Information Storage
  - Aircraft, Automobiles
  - Telecommunications

- So Why Are Current Solar Systems Designed With So Many Single Points of Failure?

RAIS Design Concept – Eliminate All Single Points of Failure

RAIS = **R**edundant **A**rray of **I**ntegrated **S**olar

Technology Generations

	Gen 1	Gen 2	Gen 2	Gen 3
	Conventional Strings	Micro-Inverter	String Optimizer	RAIS - Highly Fault Tolerant
Cell-Cell Interconnects	Single Point of Failure	Single Point of Failure	Single Point of Failure	Interconnected - Redundant (6:4)
Within Module Connects	Single Point of Failure	Single Point of Failure	Single Point of Failure	Interconnected - Redundant (6:4)
J-Box Connects	Single Point of Failure	Single Point of Failure	Single Point of Failure	Interconnected - Redundant (10:2)
Electronic Connects	None Used	Single Point of Failure	Single Point of Failure	Interconnected - Redundant (10:2)
Module Electronics	None Used	Single Point of Failure	Single Point of Failure	Fully Redundant (Fault Tolerant) (6:4)
Master Balancing System	None Used	None Used	Single Point of Failure	None Used
Module Connections	Single Point of Failure	Single Point of Failure	Single Point of Failure	Bus - All Modules Independent
Module AC Connects	None Used	Single Point of Failure	None Used	None Used
Combiner Box Connects	Single Point of Failure	Single Point of Failure	Single Point of Failure	Line Redundancy (2:1)
AFCI	Single Point of Failure	Not Required	Single Point of Failure	Not Required
OCP (Fuse)	Single Point of Failure	Single Point of Failure	Single Point of Failure	Line Redundancy (2:1)
DC Run	Single Point of Failure	Not Required	Single Point of Failure	Not Required
Inverter	Single Point of Failure	Single Point of Failure	Single Point of Failure	Redundant (5:4 or 4:3)

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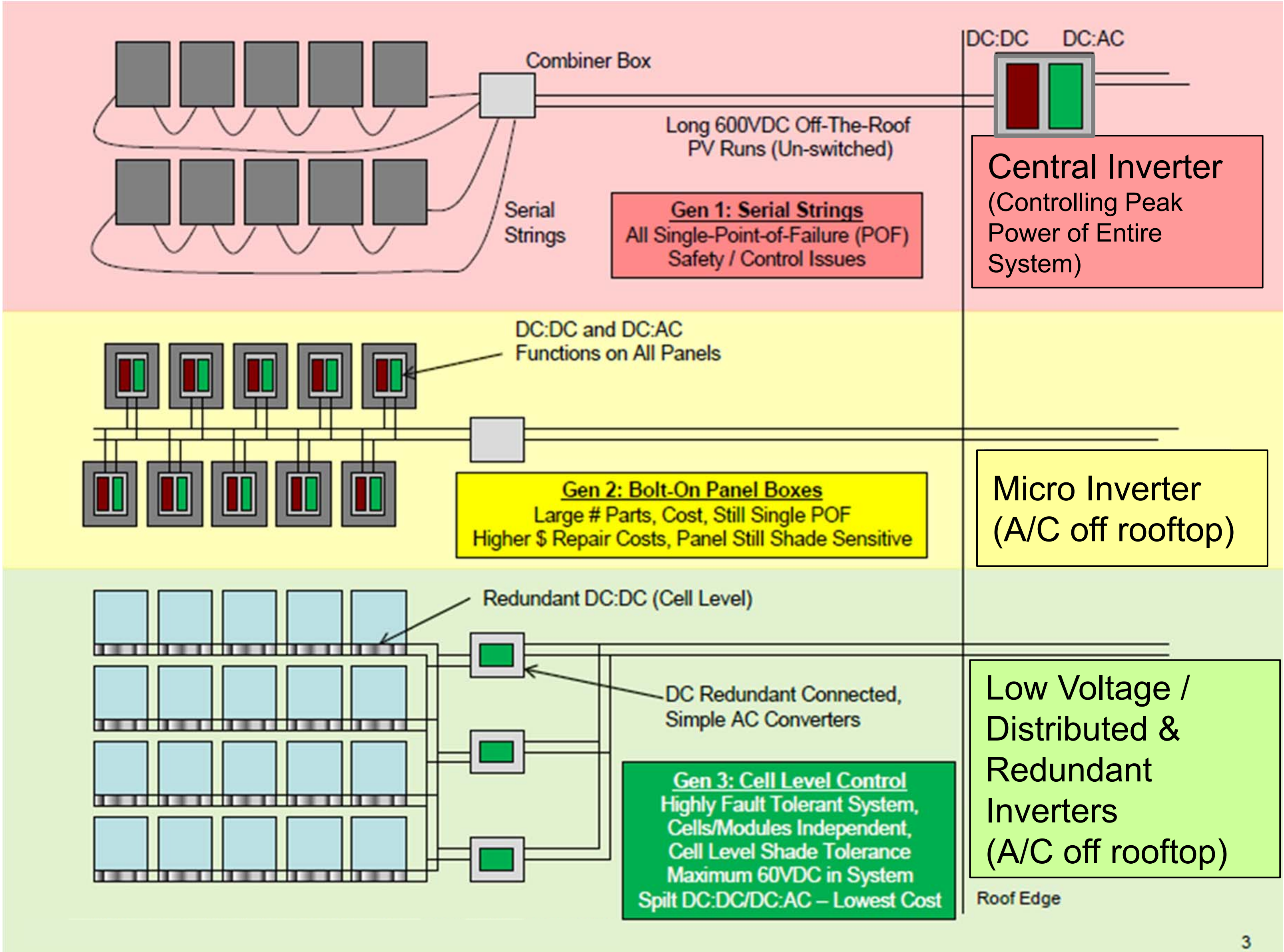
System Topologies



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Why Throw Away Power With an On/Off Switch (i.e., a Diode)?

Conventional – Portrait Mode

90% of Area With 100% Illumination

10% of Area With 90% Illumination

Condition 1:
Diodes Open
Power: 90%
(Soiled Area Limiting)

Condition 2:
Diodes Shunting
Power: 0-67%
(1, 2, 3 Shunting)

Many Diodes– Portrait Mode

90% of Area With 100% Illumination

10% of Area With 90% Illumination

Condition 1:
Base Diode Open
Power: 90%
(Soiled Area Limiting)

Condition 2:
Base Diode Shunting
Power: 90%
(10% Eliminated by Diode)

Conventional – Landscape Mode

90% of Area With 100% Illumination

10% of Area With 90% Illumination

Condition 1:
Base Diode Open
Power: 90%
(Soiled Area Limiting)

Condition 2:
Base Diode Shunting
Power: 67%
(33% Eliminated by Diode)

tenKsolar RAIS

90% of Area With 100% Illumination

10% of Area With 90% Illumination

Single State Operation
(No Diodes)

Power:
Top Area: 90%*100% = 90%
Soiled Area: 10%*90% = 9%
Total Power: 99%

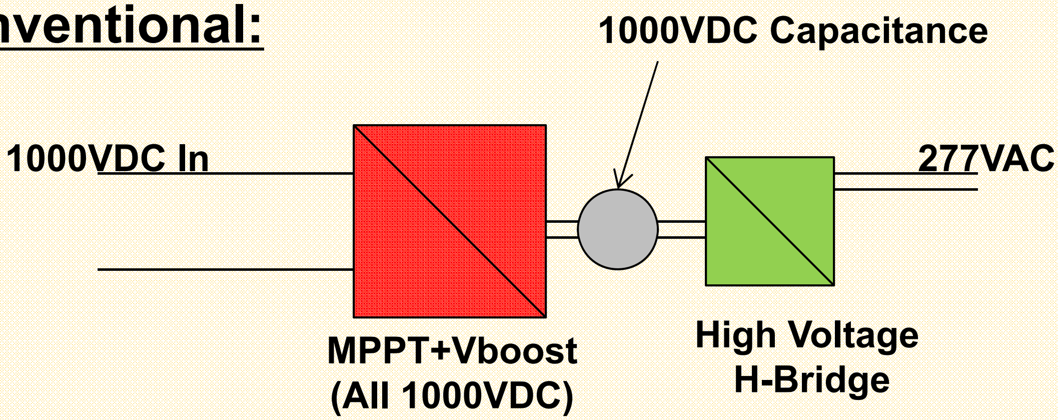
In All Condition 1 States – The Soiled Area Limits Entire Array to 90%
(Not Just the Soiled Module)

DC:AC Conversion Topology – Not Just A Scaled Down Central Inverter!

Primary Failure Mode of Active Components (FETs, Diodes, Caps, …)

Power Leakage: $V_{op}^2 / R_{leakage}$

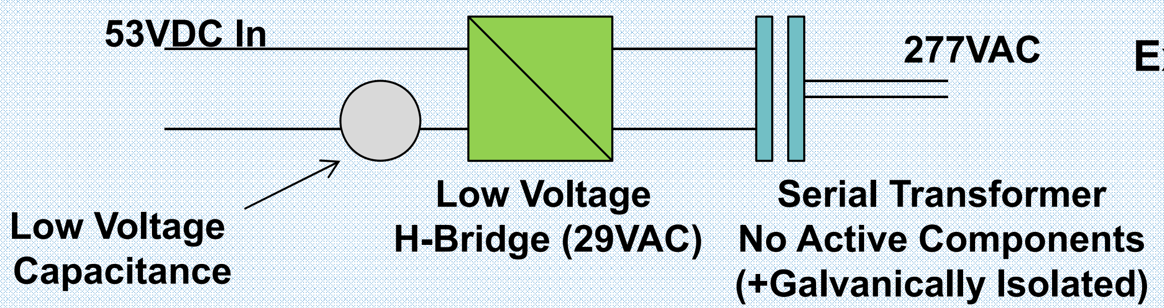
Conventional:



All Actives Exposed To 400-1000V_{peak} Voltage Stress

$P_{leakage}$= 1,000,000 / $R_{leakage}$

RAIS Wave Topology:



Active Components Exposed To <60V_{peak} Voltage Stress

$P_{leakage}$ = 2,700 / $R_{leakage}$

(Automotive Levels)

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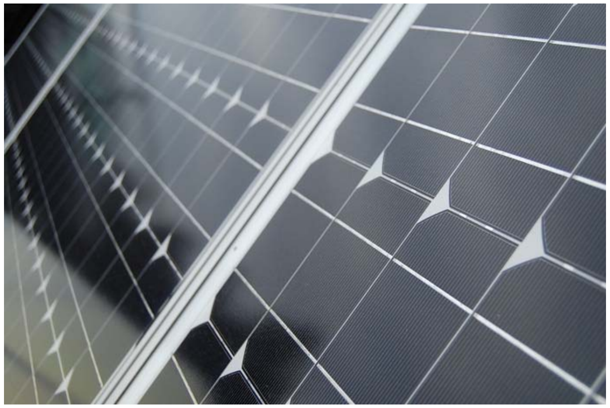
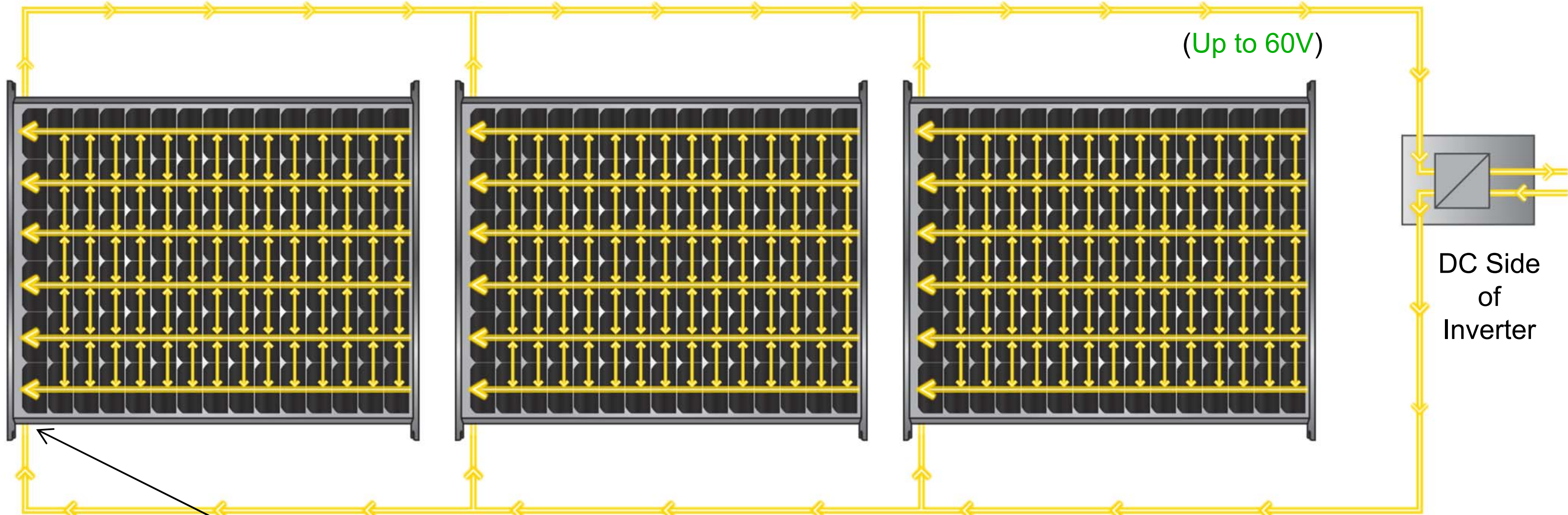
tenKsolar RAIS Module: Mesh Grid Architecture

- Soiling/Shade/Snow Tolerant
- Maximum Production with Minimal Cleaning
- Cell Level Power Optimization through Embedded Intelligent Electronics





Cell to Grid Redundant PV Array Delivers High System Availability

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Definitions:

Degradation refers to a gradual degradation of power over time, usually related to changes in specific cells gradually dragging down the system output due to the serial interdependencies in the system (the Christmas tree light architecture within a traditional solar panel).

Failure refers to a more sudden drop in power due to a failure of an individual component, such as a cracked cell, broken interconnect, inverter failure, etc.   A trip to the site for corrective action, even if it is just a simple reset required, a quick repair, etc., still constitutes a failure due to the cost of the technician + truck-roll.

Conventional module is any solar panel except a tenKsolar module.

tenKsolar module is a module designed to eliminate all single point of failure points and serial interdependencies across the entire system. A problem with any individual cell, interconnect, panel leads, MC connectors or even the inverters do not lead to significant losses of power, creating an unprecedented level of reliability. The module is called a RAIS module (Redundant Array of Integrated Solar).

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Comparison of System Response to Component Failure Modes

Failure mode	In conventional modules	In tenKsolar modules
Failed Cell Interconnections (interconnections between cells fail, due to latent defects or hot/cold stress over time)	Power drops entire string output by 30-100%, fails other interconnects over time.	No cell-cell interdependency, many current paths through module, output drop is negligible. No long-term stress issues.
Cracked Cell Within Single Panel (cell develops crack due to latent defects, wind buffeting, hot/cold stress over time)	Power drops entire string output by 10-100%, depending on shape and location in cell. Added degradation long-term.	No cell-cell interdependency, output drop negligible. No long-term stress issues.

Comparison of System Response to Component Failure Modes

Failure mode	In conventional modules	In tenKsolar modules
Cell Cracking Within Panel Due to Wind Buffeting or Snow Deflections (initial micro-cracks within cells extend and run across the cell resulting in a full crack)	Each deflection from the face (wind or snow) flexes the cell, eventually leading to fatigue failure in the cell (crack advances).	Material stack used creates an in-plane compressive stress across the cells, avoiding formation of tensile stresses in the cells from wind or snow.
Cell Shading Due to Snow or Soiling (partial coverage of the module with snow or non-uniform soiling creates mis-matches within the array)	Localized snow on a single panel, or preferential soiling along the lowest cells, reduces production in the entire string.	The cells are not dependent upon each other, therefore non-uniform soiling or snow partial coverage only impact the covered areas, not the unaffected cells or array.

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Comparison of System Response to Component Failure Modes

Failure mode	In conventional modules	In tenKsolar modules
Solar Cell Degradation (light induced degradation, increased internal shunting losses due to poor edge trimming, water ingress creating added shunting shorts, lifted screen printed collectors, or other loss of current production within one cell)	Entire string drops with single cell, bypass diodes are of no help because it is only a partial loss of production.	No cell-cell interdependency, output drop negligible. No long-term stress issues from cell-cell imbalance.
Hot Spot Failures (mismatched, cracked or shaded cells lead to hot spot failures over time)	Affects module or possibly entire string depending on severity.	Cell-cell independence and low voltage operation eliminates possibility of hot spots.
Failed Internal Panel Interconnection (failures of the internal panel leads connecting the Jbox)	Power drops entire string output by 100%.	There is no panel routing leads, all connections are highly redundant.

Comparison of System Response to Component Failure Modes

Failure mode	In conventional modules	In tenKsolar modules
Module-Module Connection Degradation (MC connectors degrade due to field workmanship, moisture ingress, rubber cord cracking / degradation, excessive stress where leads are pulled, pinched leads, etc.)	Entire string power degrades due to added resistance within string.	Modules are connected in parallel, utility style connectors, utility grade wire, and no module-module interdependency.
Module Delamination (material stack of the module separates, due to workmanship, poor materials, or moisture ingress due to temperature/humidity exposure)	Individual cells affected due to air gaps (optical loss), corroded contacts, etc. – often power loss on a string of 100%.	Modules use best-in-class material suppliers and a metal backsheet and metal-glass edge seal to avoid moisture ingress.

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Comparison of System Response to Component Failure Modes

Failure mode	In conventional modules	In tenKsolar modules
Moisture Ingress Into the Module (conventional panels use plastic backsheets that allow moisture to pass into the panel over time, degrading the adhesives, corroding the contacts, shunting the cells, etc.)	Degradation occurs over time due to impact on encapsulants, cell shunt growth due to ionic contaminants, electrochemical corrosion of interconnections.	Modules use metal backsheet and metal-glass edge seal to avoid moisture ingress, irrespective of installation conditions.
Temperature Related Degradation (cells, conductors and and encapsulants are all very sensitive to temperature, and conventional panels have NOCT values of >45ºC, when installed in closed racks operate at temperatures and even higher when installed adjacent to the roof)	Higher temperatures result in power loss, and accelerated degradation of the panel.	Modules have a very low NOCT of 41ºC, and are installed open and roof temperatures are reduced by the reflectors.
Ground Fault Fuse Failures (ground fault fuses within inverter fail due to leakage currents, require technician service to replace)	Complete system failure, no output until serviced.	Low voltage operation, negligible leakage currents.

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Comparison of System Response to Component Failure Modes

Failure mode	In conventional modules	In tenKsolar modules
System Fuse Failures (fuses fail due to current spikes from weather (cloud edges), component issues, etc.)	Entire loss of string production with single fuse failure.	Each module is internally current limited, parallel fuse rating of up to 80A.
Bypass Diode Failure (bypass diodes degrade due to undersizing and/or overheating and low quality manufacturing, when failing open they present a very significant fire hazard to the entire array)	When failing short, loss of panel power and large temperature rise in Jbox, when failing open no longer prevents reverse biasing of cells (fire hazard).	No bypass diodes are used. Cells are never exposed to large reverse bias voltages.
Jbox Failure or Attachment Failure (failure of the Jbox when attached to the panel, or failure within the Jbox often resulting in melting / deformations)	Jbox falls off presenting hazard to all, melting / deformation results in loss of power for full string.	Electronics integrated into module, entire back of module is metal (not plastic), connectors attached using metal-metal connections.

Comparison of System Response to Component Failure Modes

Failure mode	In conventional modules	In tenKsolar modules
Bypass Triggers Due to Shading, etc. in One String (with many strings in parallel through a combiner box)	Entire string drops in power due to operating at non-peak power conditions (voltage offset from other strings, voltage set at central inverter)	Cell-cell power optimization completed internal to module, no dependencies outside the module.
Inverter Failures (inverter fails for ground fault, internal faults, component failure, etc.)	All interconnected strings are affected.	Current flows to other inverters. Given profile of typical solar day – minimal impact to power production.
Module Glass Breakage (Shattering of the top glass surface can occur due to vandalism, thermal stress, handling, wind or hail.)	Affects entire string of modules, significant current leakage, significant safety and fire hazard.	No affect on other modules – no safety risk, module cannot arc (low voltage) and will stop making power if a fault occurs.

Comparison of System Response to Component Failure Modes

Failure mode	In conventional modules	In tenKsolar modules
Confirmation of Degradation or Failure (diagnosing a conventional module failure is difficult – trial and error to isolate a defective panel)	Technician spends time jumpering high voltage modules and repeated covering / cycling the system to find defective components. Warranty disputes typical after identified as it may not repeat outside of the string.	Digital diagnostics, communication system and front side visible LED allow rapid detection and corrective actions. No warranty disputes.

Conclusion:

By thinking about reliability as a system requirement, and re-architecting the system accordingly, tenKsolar has designed out all of the major failure modes found in conventional solar systems today. As a result, tenKsolar delivers the most reliable solar array found on the market today.

Oh..BTW…RAIS Sets the PV Safety Standard!

- Modules < 10V – no arc risk in panel
- RAIS Modules provided continuous monitoring
  - Check if Live Circuit?
  - If Not – Module remains isolated
  - Uses Analog device
- Autonomous, Integrated GFDI
  - Limits risk of double ground fault in conjunction with inverter ground fault detection
  - Limits time duration of any possible system arc

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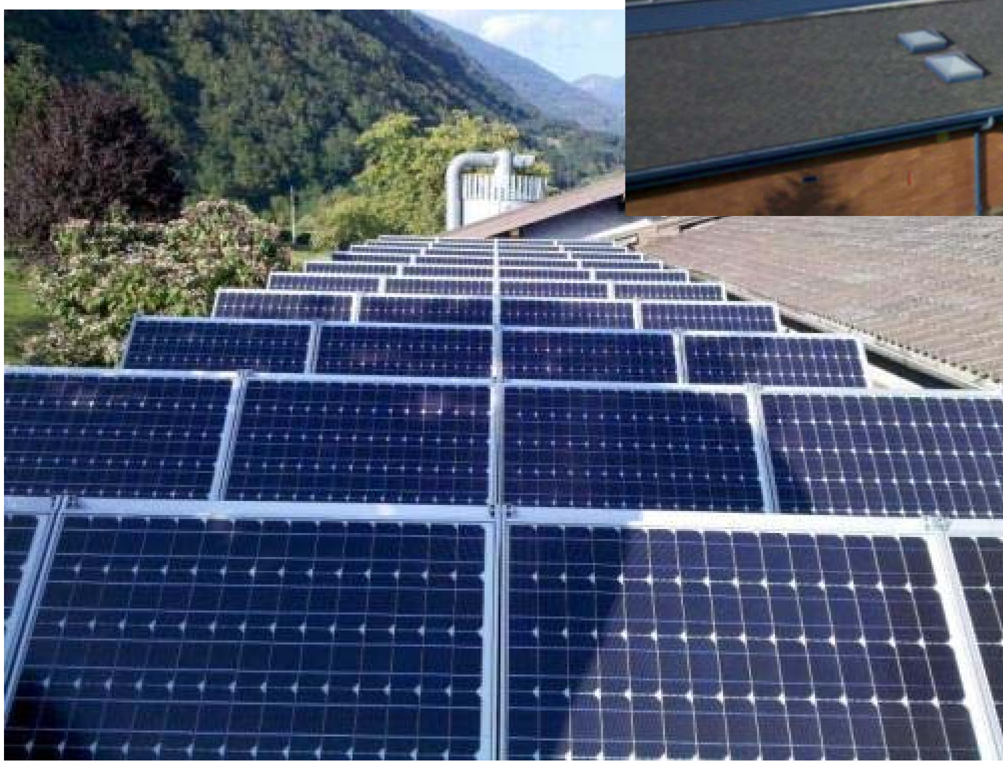

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