Panel Level Power Electronics-
From vision to commercial reality.

Jeff Routledge
Director Pacifica
Tigo Energy

Outline

- Insiders view in relation to DC Power Electronics
  1. Introduction
  2. Development
  3. Commercial reality (Bankability)

- The important role of DC Power Electronics in the current PV market
- New developments in Smart Module technology

Choice Electric Co.
Brisbane

Products

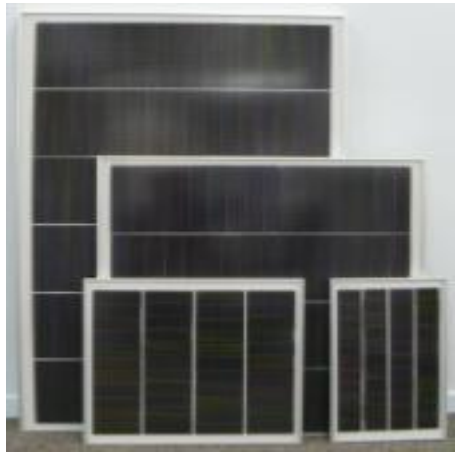
Inverters

- Fronius IG
  - 1.kW – 6kW
- Fronius IG Plus
  - 4kW – 12kW
- Fronius IG Central
  - 30kW – 50kW
- Fronius IS
  - 2200W
- IG.*access*
- Self Diagnostics
- Extensive Data Monitoring Options

Products $5.35 per watt

Solar Panels

- Sharp High Performance Modules
  - 80W
  - 123W
  - 175W
- CIGS
  - 6W
  - 12W
  - 25W
  - 60W



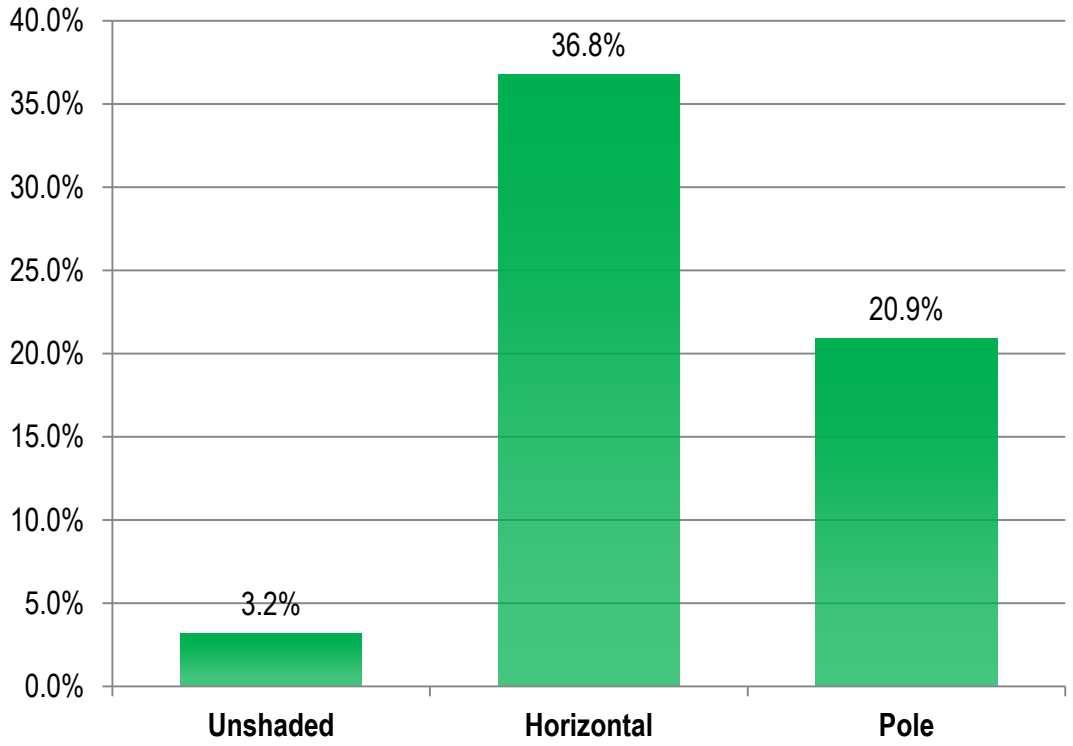
Outline

- Insiders view on DC Power Electronics
  1. Introduction

Solar Magic

- DC optimization without monitoring
- Typical system size 1kW – 2kW (6 to 12 panels)
- Cost effective based on high system costs

Photon International Study



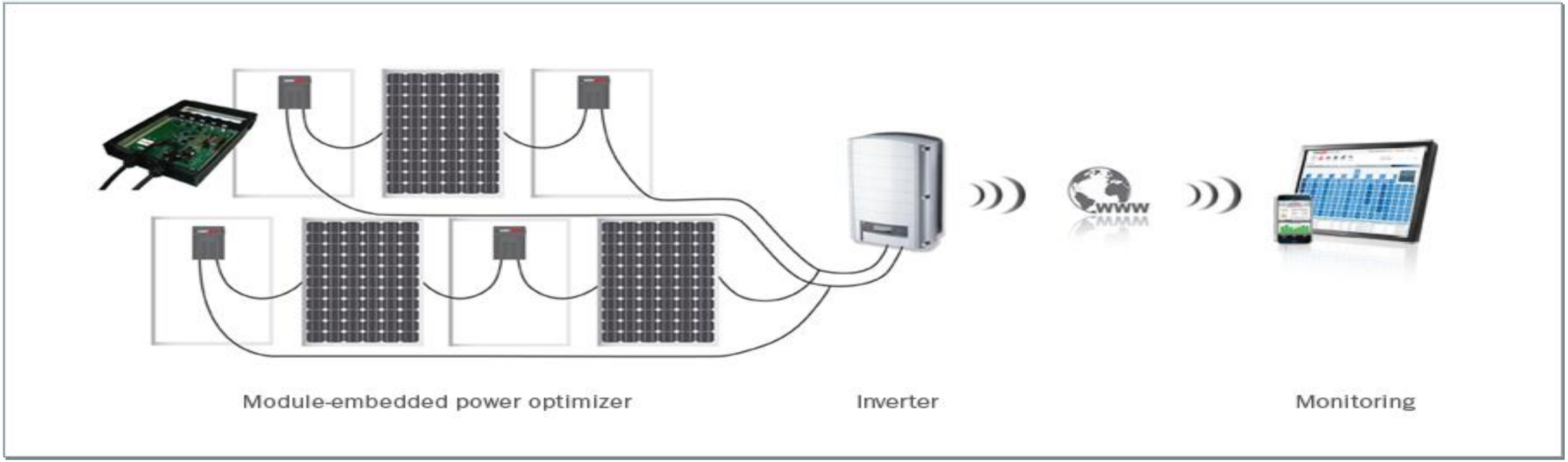
Shade Description:	No obstructions	Flat shade object placed across four modules, with height of approx. 1 cell	Pole placed across array, with shadow touching 3-4 modules

Source: Photon International, November 2010. Test system is 2.5kW array using Trina 180W modules

Outline

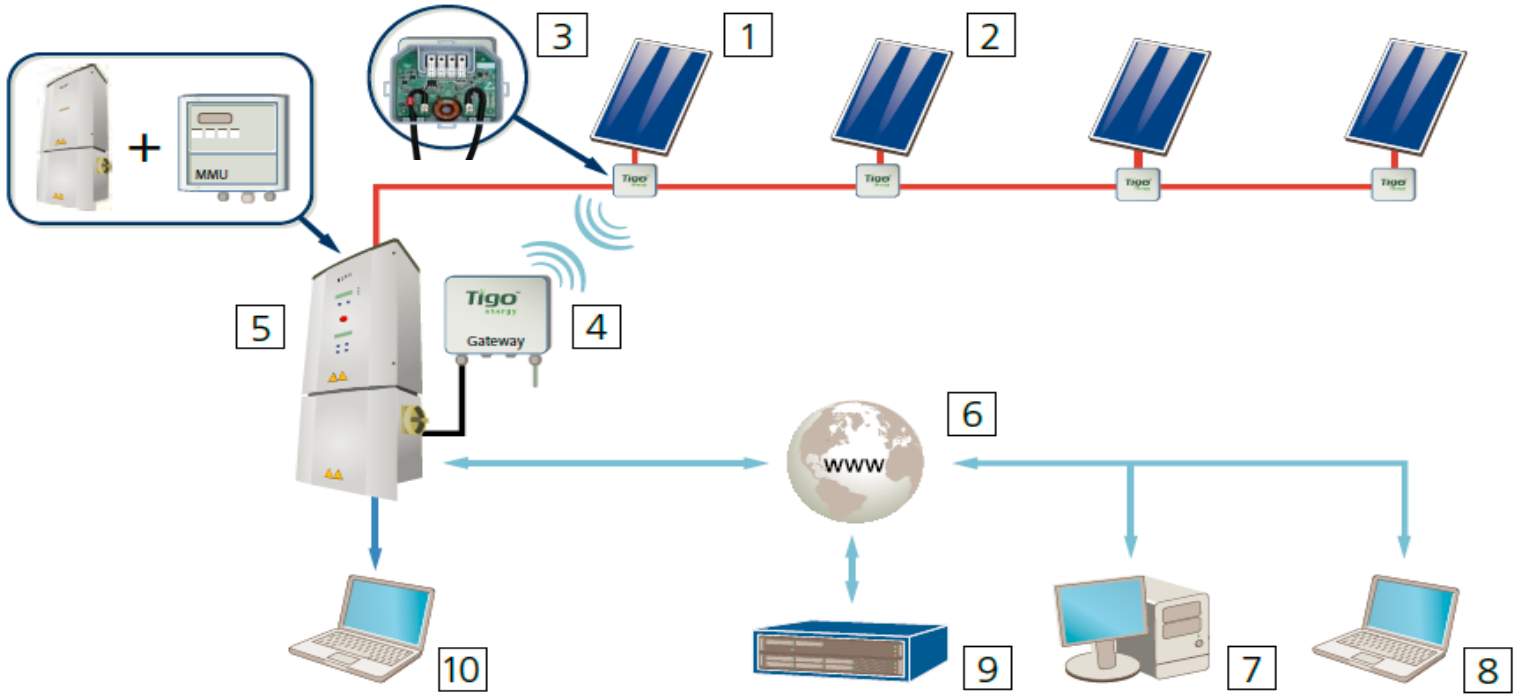
- Insiders view on DC Power Electronics
  2. Development

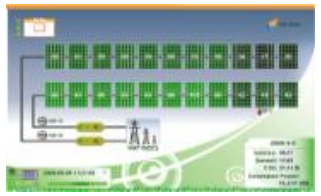
SOLCO
CHOICE ELECTRIC



Anatomy of a SmartInverter™

- Integrate MMU
- Eliminate Boost
- Reduce MPPT
- Improve safety/disconnect
- Improved Monitoring
- Anti-theft
- Voltage control
- Arc Fault





Safe Solar

Smart Modules Optimized by Tigo Energy have additional safety features that protect buildings and emergency personnel in the event of problems. Tigo's technology meets new code requirements.

Region	Code	Date
Germany	VDE-AR-E 2100-712	2014
Austria	11-1:2013	2013
USA	NEC 2014: 690.12	2014
France	C15-712	2013

- **Module Level Deactivation** – Smart Modules can be deactivated so that they produce no voltage or current to the DC bus
- **Regulations –** Safety codes are mandating this capability, see chart on the left with all new code requirements
- **Arc** – Smart Modules Optimized by Tigo Energy can detect over-voltage, over-current, and over-temperature and automatically deactivate. When paired with Tigo's Arc detector the technology meets UL1699b requirements.
- **Deactivation –** Occurs automatically in the event of a detected arc or if an emergency person throws the AC breaker. Can also be done manually at the Management unit or via the software.

Module-Level O&M: Case Study

- 9-Year-Old System Retrofit
- 30% Immediate Improvement
- Many Issues Quickly Assessed After Years of Going Unnoticed

Market Conditions at Development

- Panel pricing has plummeted below $2.00 per watt (increasing % cost that optimizers are adding to the system.
- We saw poorly planed, implemented and poorly coordinated state based feed in tariffs ravaging the industry, causing product shortages
- RET pricing was fluctuating wildly
- This lead to a flood of new low cost inverters as well a tier 2 & 3 panels entering the market to fill this void.
- **The flow on effect:** we see sellers at this time begin using pricing as a sales tool in order to win business (further killing the industry).
  NOTE In sales pricing typically only goes on way (down)

My Manager at the time told me these products “Solar Edge & Tigo” would never sell because they added to great a cost to the system, and it was all about cost.

Danger

- The Chines word danger is made up of two component parts; **danger - opportunity.**

- And so all my manager could see was danger, but all I could see was opportunity.

Market Opportunities

- System sizes had grown significantly with 10kW and 20kW becoming common. (46 panel – 92 panels).
- Many system failures due to Poor quality components, highlighted the need to better monitor and understand the health of these assets.
- Many sellers who were selling on price were being forced out of business
- The remaining sellers began looking for ways to differentiate there offerings by **adding value** and margin to their offerings.
- Forms of system shading became more prevalent and accepted, because of low panel costs.
- **Customers** wanted to see and validate that there systems were working.

Outline

- Insiders view on DC Power Electronics
  3. Commercial reality (Bankability)

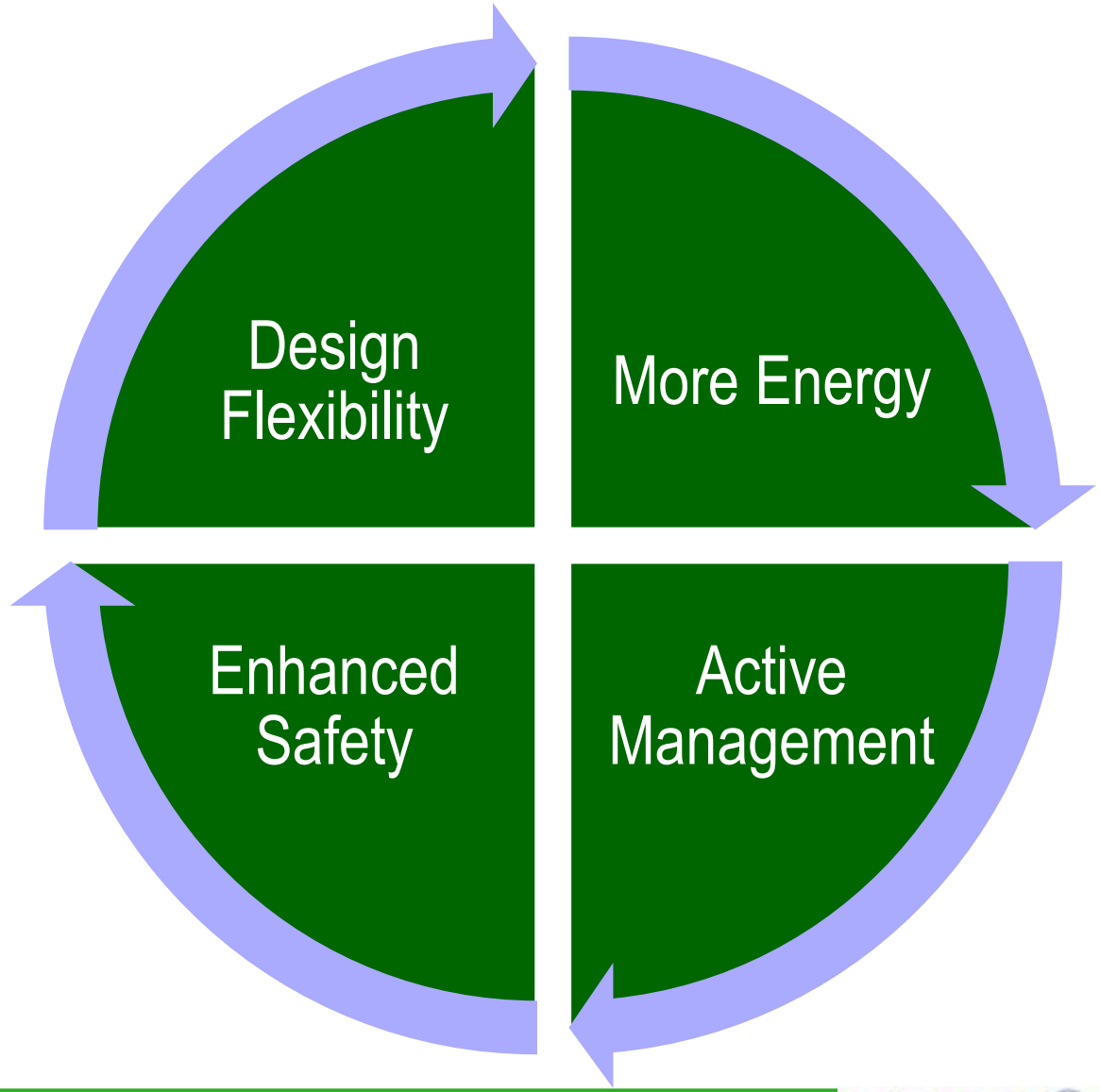
Tigo Components

Trinasmart

Smart Module:

- Tigo Maximizer technology built into a PV module to become a Smart Module

Benefits of Distributed Electronics?



Websters 1828 Dictionary

- **Risk**
- RISK, noun
- 1. Hazard; danger; peril; exposure to harm. He, at the risk of his life, saved a drowning man.
- 2. In commerce, the **hazard of loss,** either of ship, goods or other property. Hence, **risk signifies also the degree of hazard or danger**; for the premiums of insurance are calculated upon the risk The underwriters now take risks at a low premium.
- To run a risk is to incur hazard; to encounter danger.
- RISK, verb transitive
- 1. To hazard; to endanger; to expose to injury or loss; as, to risk goods on board of a ship; to risk one's person in battle; to risk one's fame by a publication; to risk life in defense of rights.
- 2. To venture; to dare to undertake; as, to risk a battle or combat.

Free Dictionary On Line

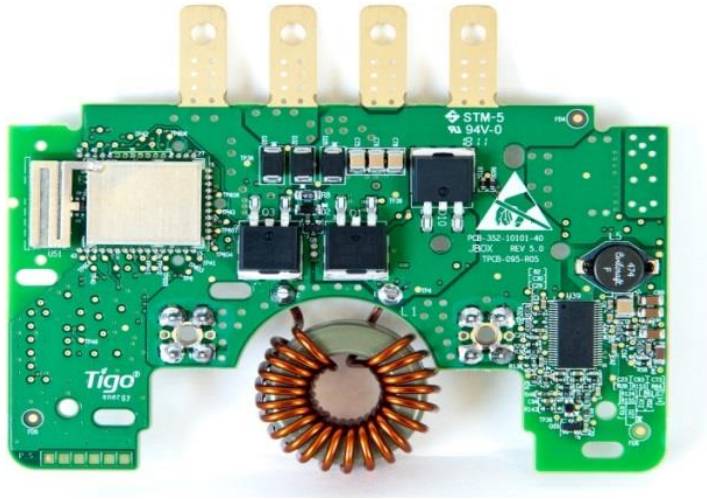
- bank·a·ble (băng′kə-bəl)

adj.

- 1. Acceptable to or at a bank: bankable funds.
- 2. Guaranteed to bring profit

Smart Module Technology

Tigo Energy's Smart Module Technology is designed using a patented impedance matching technology, which uses high frequency switching rather than buck / boost transformers to achieve industry leading efficiency, cost, and reliability



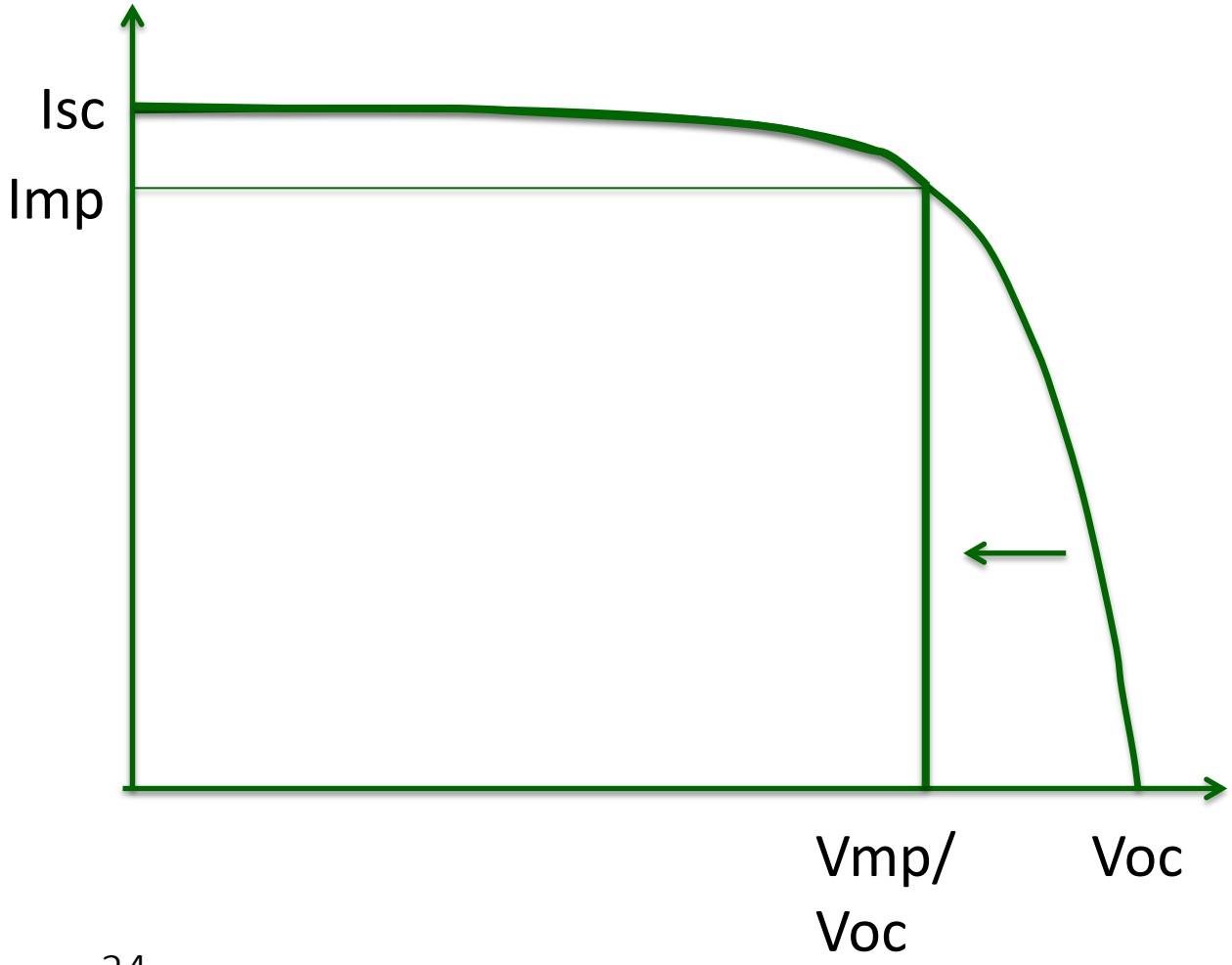
- **Highest Efficiency** – The most efficient solution in the industry at 99.6% CEC weighted efficiency as compared to 98.5% CEC weighted efficiency for next best
- **Lowest Part Count** – Less than 100 components, 2 times fewer than any other solution
- **Duty Cycle** – Works only when mismatch is present, otherwise the technology is just monitoring without any conversion
- **Heat** – High efficiency results in little to no heat generated in the junction box of a solar module.
- **Reliability –** Industry leading MTBF of over 1000 years

Reliability

Tigo Energy's design philosophy is to distribute as few electronic components to the module as possible to maximize reliability and minimize maintenance. Tigo Energy's technology is designed to last well beyond 25 years and comes standard with a 25 year warranty.

- **Third Party –** BEW Engineering and DNV corp. have audited Tigo Energy's technology and provided positive bankability reports. Newest generation has industry best 1000+ year MTBF.
- **Proven in the Field –** Over 1 million units in the field with less than 0.08% failure rate
- **Failure Mode –** Tigo's Smart Module technology is the only Smart Module technology that fails "benign" – meaning the module will still produce power if the electronics fail
- **Jbox –** Tigo Energy works with Tier 1 Jbox manufacturers Amphenol, Flextronics, and Leoni (all $3B+ companies) who have designed junction boxes that are field replaceable in the event of electronics failure

Tigo Energy Enables Longer Strings



Strings 20% longer

Electrical balance of systems 20% cheaper

Patented Smart Curve Technology

Max Voltage

- Programmed at factory
- Not temperature dependent

Certification

- UL1741, EN62109-1
- TUV, CSA spec approved
- Compliant with IEC and NEC

Benefits

- 30% longer strings
- 30% lower I2R losses
- Fewer BOS components
- More efficient inverters

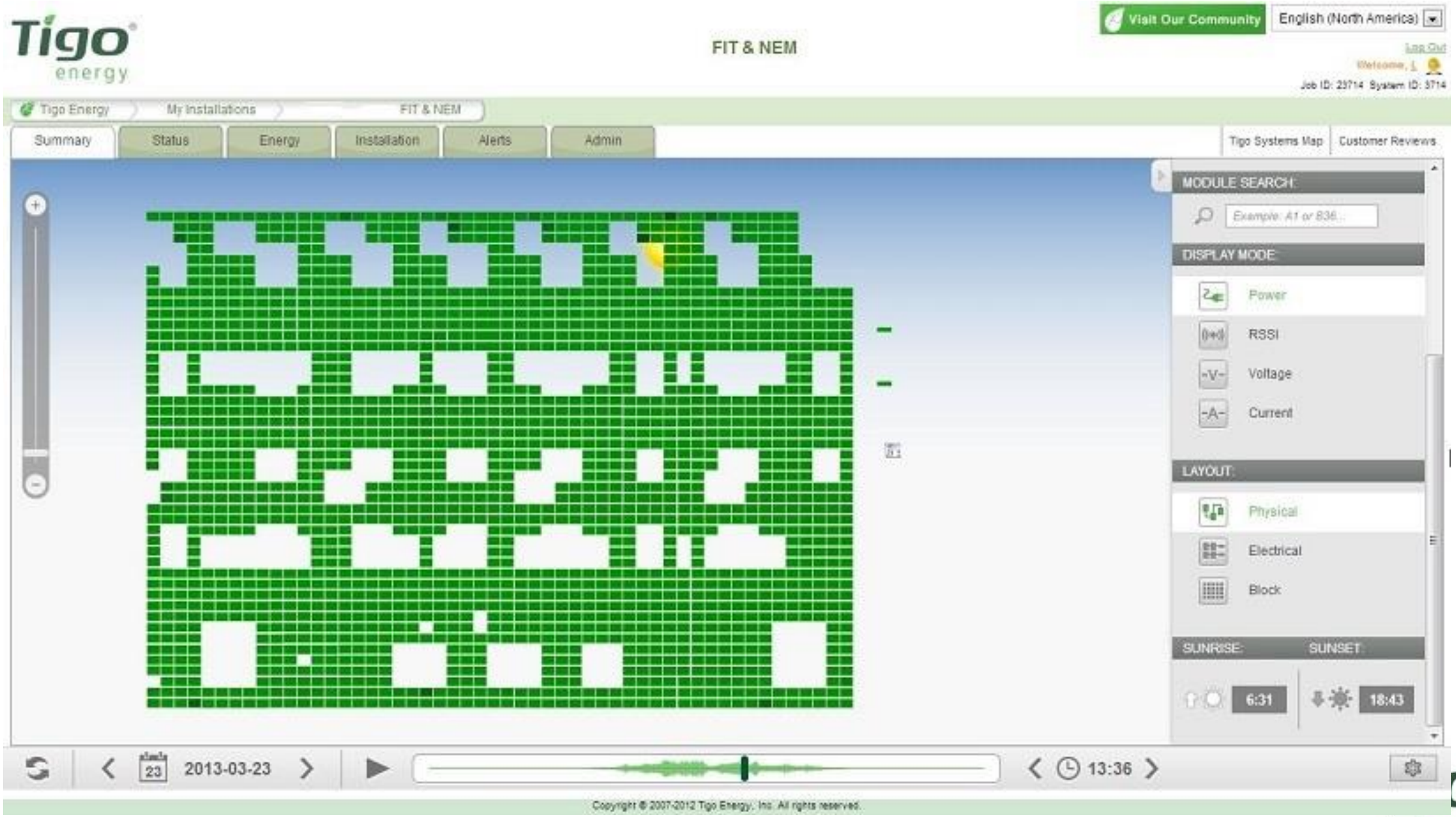
String Length

Electrical Specifications

	60-Cell	Smart Curve	72-Cell	Smart Curve
Vmp	29.7	**29.7**	36.1	**36.1**
Voc	37.3	**31.5**	44.9	**38.3**
V (-10C)	41.0	**31.5**	49.4	**38.3**
Fill Factor	75%	**89%**	76%	**89%**
600V String Length	14	**18**	12	**15**
1kV String Length	24	**31**	20	**26**
1.5kV String Length	36	**46**	30	**39**

Example:

- Commercial roof
- 1,803 panels
- 400kW system
- 6 MMUs
- 22 Gateways
- Gateways spaced around obstructions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Status
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Installation
Alerts
Admin
Tigo Systems Map
Customer Reviews
MODULE SEARCH:
Example: A1 or B36...
DISPLAY MODE:
Power
RSSI
Voltage
Current
LAYOUT:
Physical
Electrical
Block
SUNRISE:
SUNSET:
6:31
18:43
2013-03-23
13:36
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SVG Chart - Mozilla Firefox

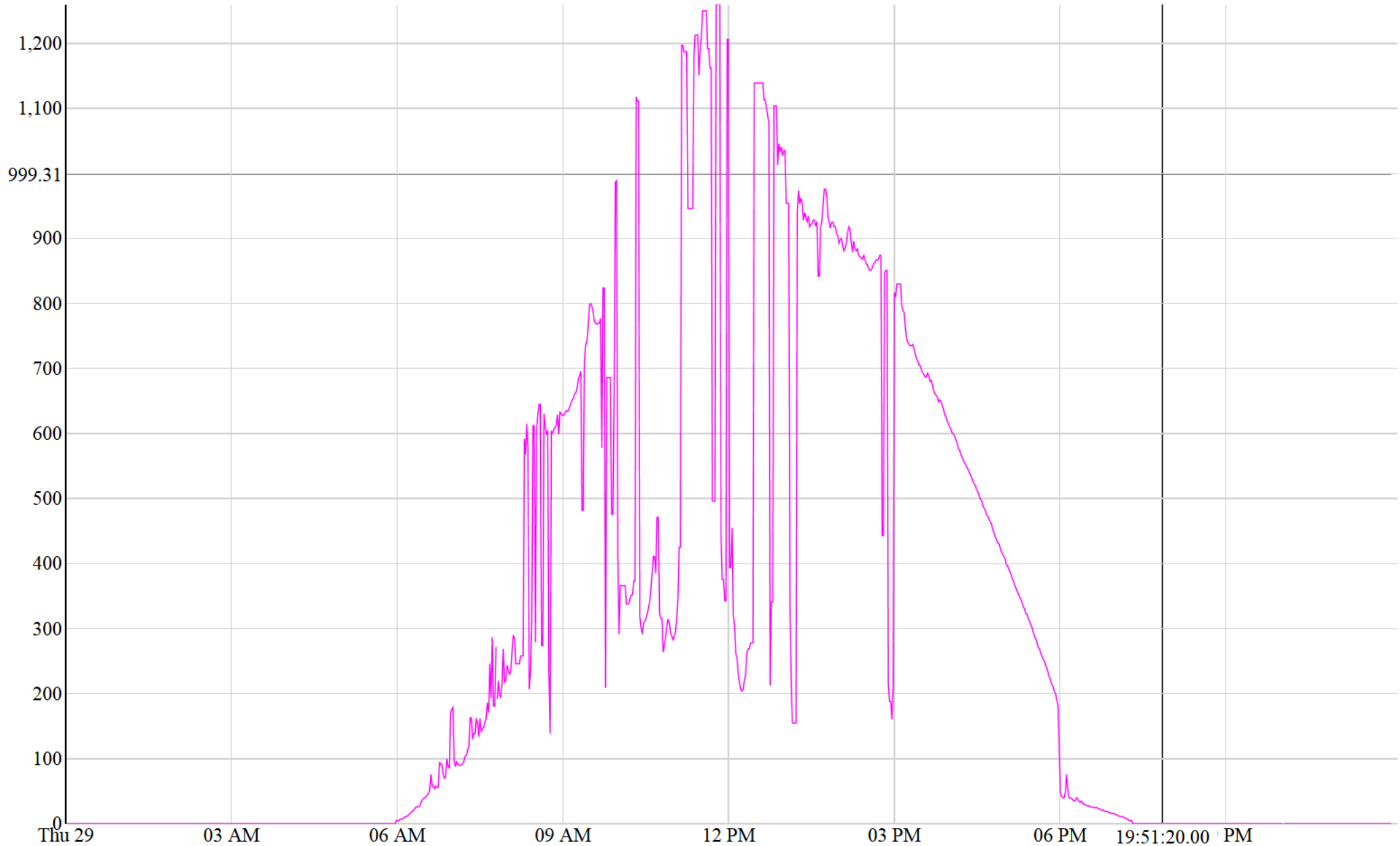
https://installations.tigoenergy.com/charts/graph2.php?sysid=9123&from=2015-10-29_00-00-00&to=2015-10-29_23-59-60&uid=04C05B80542B&freq=1&src=OceanGWY&power=1&lmus=&json=1

Time 2015/10/29 19:51:20.00

Norm | Center | Width: 1 | Auto | Reset

1,079 / 8,640

InsideAlarm	0
LeafTemp1	-1
LeafTemp2	-1
LeafWetness1	-1
LeafWetness2	255
MonthET	3.94
MonthRain	1.26
NextDataPacket	1268
OutsideAlarm	0
PacketType	0
PressureScale	0
RainAlarm	0
RainRate	0
RainRateScale	0
SoilLeafAlarm1	0
SoilLeafAlarm2	0
SoilMoisture1	-1
SoilMoisture2	-1
SoilTemp1	-1
SoilTemp2	-1
SolarRadiation	0
StormRain	0
TempInside	70.8
TempOutside	64.4
TempScale	0
TimeSunrise	29
TimeSunset	1115
TransmitterBatteryStat	0
UVIndex	0
WindSpeed	1
WindSpeedScale	0




UNSW School of Photovolt...
Installations
Summary - Tigo Energy
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https://installations.tigoenergy.com/base/main/summary?sysid=9123
bankability
Most Visited
Getting Started
Constant Contact : Login
Solar Optimizer and P...
User Login - Tigo Ener...
CRM & Cloud Comput...
Video: Sanctification
Systems Page
Why I Believe The K...
King James bible bu...
Tigo
Tigo Australia
English (North America)
Log Out
Welcome, Jeff Routledge
Job ID: 29123 System ID: 9123
Tigo Energy
My Installations
Tigo Australia
Summary
Status
Charts
Installation
Alerts
Admin
Help Center
268
263
0.27
0.26
Panel Info
B1
Max Output: 250 Watts
Channel: 04C05B80542B.26
Serial: 0010121759
80 W/m²
1132 W/m²
INSTANTANEOUS PRODUCTION:
0.53 kW
10:54
0 kW
0.54 kW
2015-10-30
Energy generated: 2.67 kWh
Kettles boiled: 27
CO2 Saved: 1.40 kg
Lifetime production
MODULE SEARCH:
Example: A1 or B36...
DISPLAY MODE:
Power
RSSI
IMF
Temperature
Voltage
2015-10-30
10:54
Optimized by Tigo Energy. Copyright © 2007-2015 Tigo Energy, Inc. All rights reserved.
6:46 PM
30/10/2015


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MODULE SEARCH:
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DISPLAY MODE:
Power
RSSI
IMF
Temperature
Voltage
Current
LAYOUT:
Physical
30
2015-10-30
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Screenshot Added
A screenshot was added to your Dropbox.
6:46 PM
30/10/2015

4. Web Interface

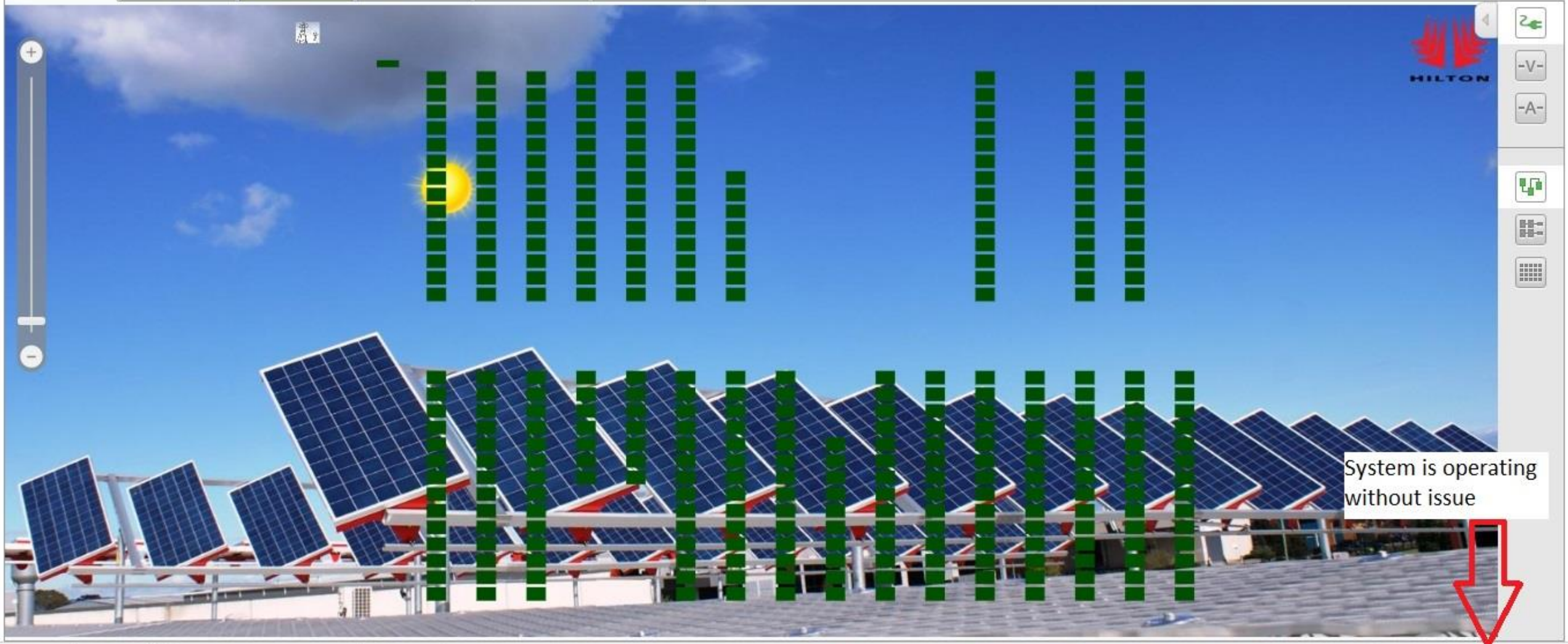
Operations & Maintenance

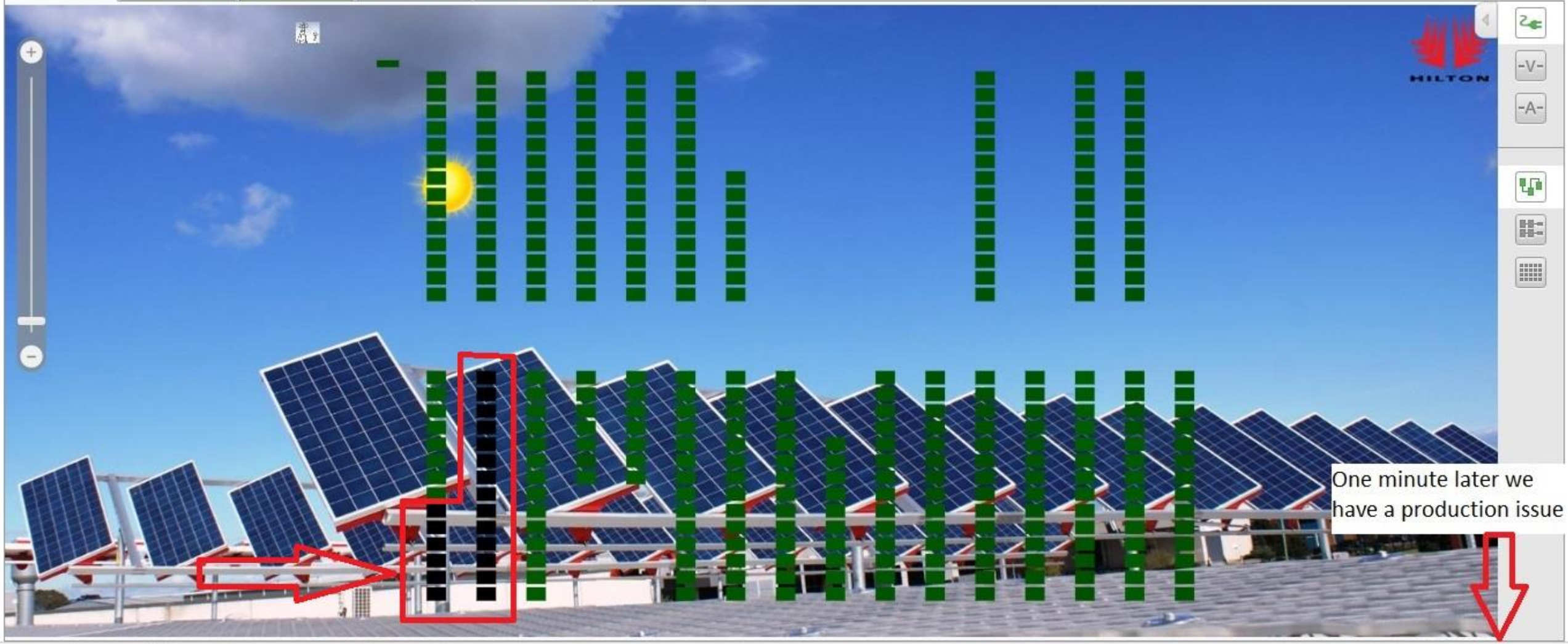
- Identify and pinpoint system maintenance issues
- System notifications
- Production reports
- Provides data to make decisions on when to service a installation

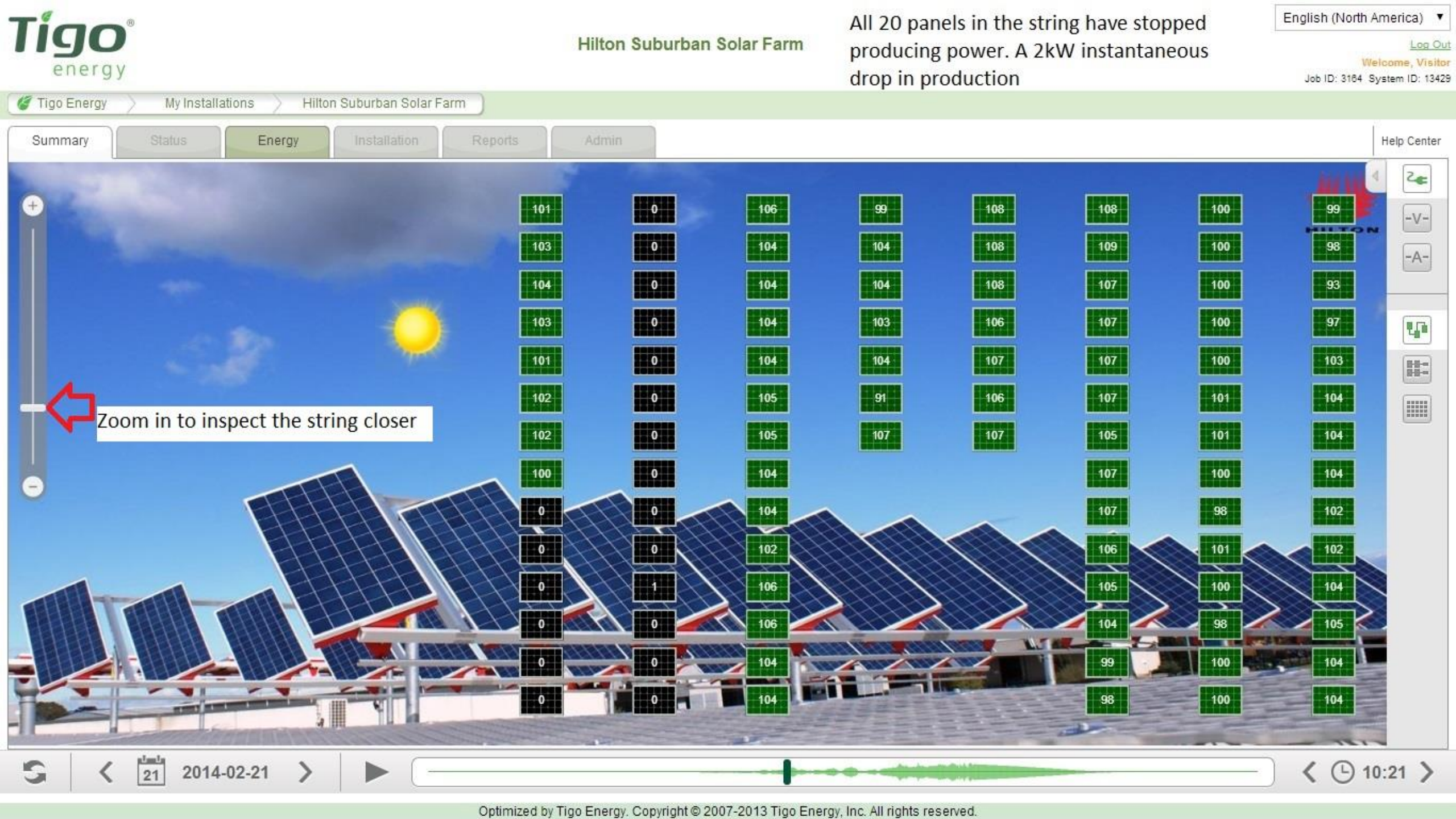
Tigo Public Website Demo

- Hilton Suburban Solar Farm
- Located in Victoria Australia
- Tigo system open to the public online

Hilton Suburban Solar Farm





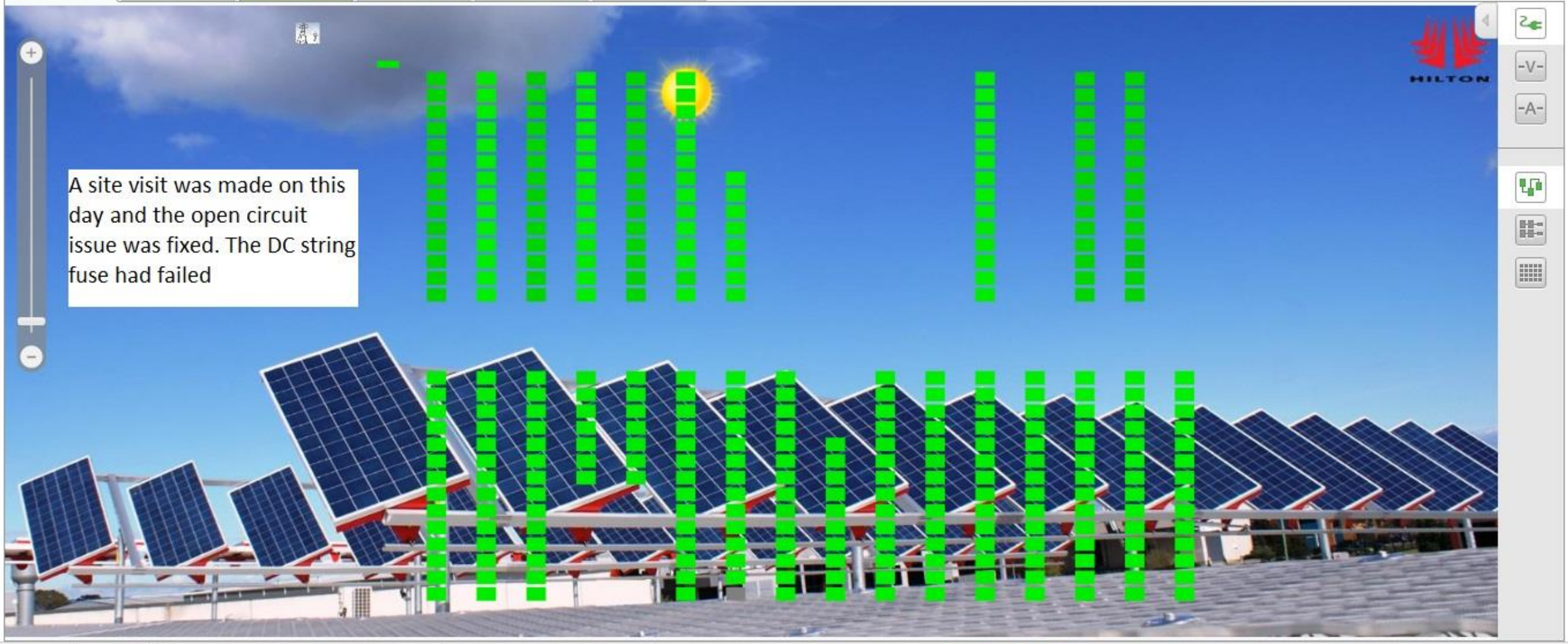

Tigo energy
Hilton Suburban Solar Farm
All 20 panels in the string have stopped producing power. A 2kW instantaneous drop in production
English (North America)
Log Out
Welcome, Visitor
Job ID: 3164 System ID: 13429
Tigo Energy
My Installations
Hilton Suburban Solar Farm
Summary
Status
Energy
Installation
Reports
Admin
Help Center
Zoom in to inspect the string closer
2014-02-21
10:21
Optimized by Tigo Energy. Copyright © 2007-2013 Tigo Energy, Inc. All rights reserved.

Hilton Suburban Solar Farm

Checking the voltage data and you can see the modules are at 44 volts, Voc, compared to 36 volts, Vmp, for the panels that are producing power

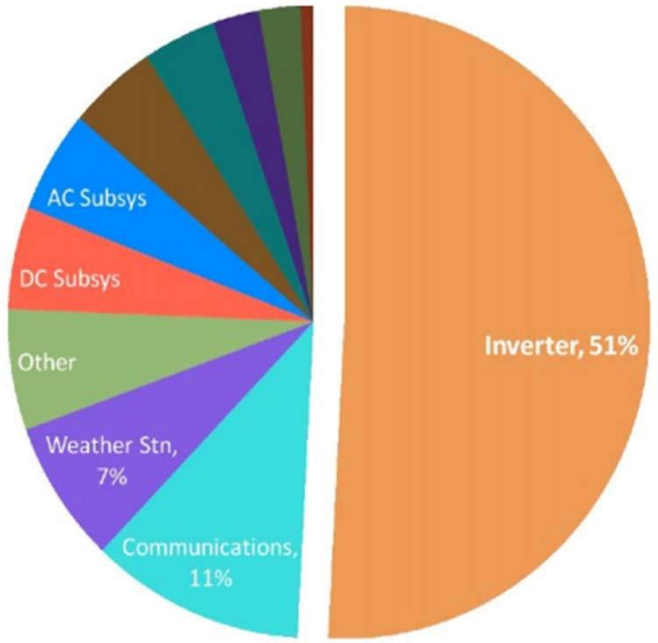
Checking the current view we can see that the inverter is not able to draw current from this string. Given the DC voltage and current information, we can conclude there is an open circuit on this string.

Hilton Suburban Solar Farm



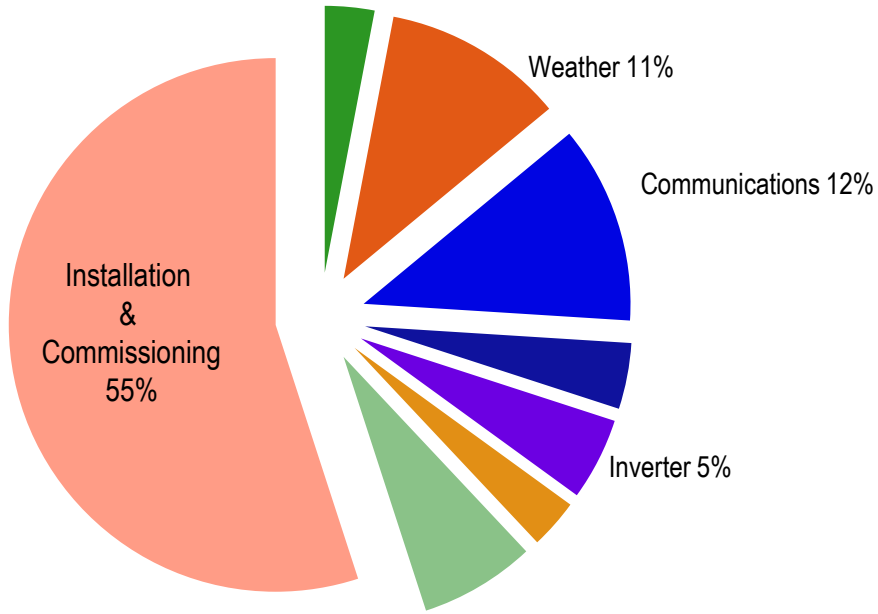
Breakdown of PV Failures

Frequency of failures per affected subsystem, SunEdison, 2008-2010



Source: SunEdison. (2011, January). *Owner/Operator Perspective on Reliability Customer Needs and Field Data.*

Frequency of failures per affected subsystem, Tigo Energy Australia 2013-2014



Tigo®

PV 2.0

About Tigo Energy

- HQ in Silicon Valley, CA
- Sales and support offices worldwide
- Installed at over 18,000 sites
- Over 1 million units shipped
- Applied for 53 patents, 18 granted
- Installed worldwide; Australia, China, Japan, Middle East, Europe, Americas, Antarctica

Tigo at a glance

- **Installation ranging from small residential to 7MW**
- Majority of installations - Commercial
- Several Hybrid systems including off grid (batteries)
- OPEN SYSTEM installed with +2000 inverter types
- The FIRST to ship a PV INTEGRATED solution
- The FIRST to ship an Inverter INTEGRATED solution

Tigo®

What is new in OEM Smart Modules? TS4?

Tigo® Introduces TS4

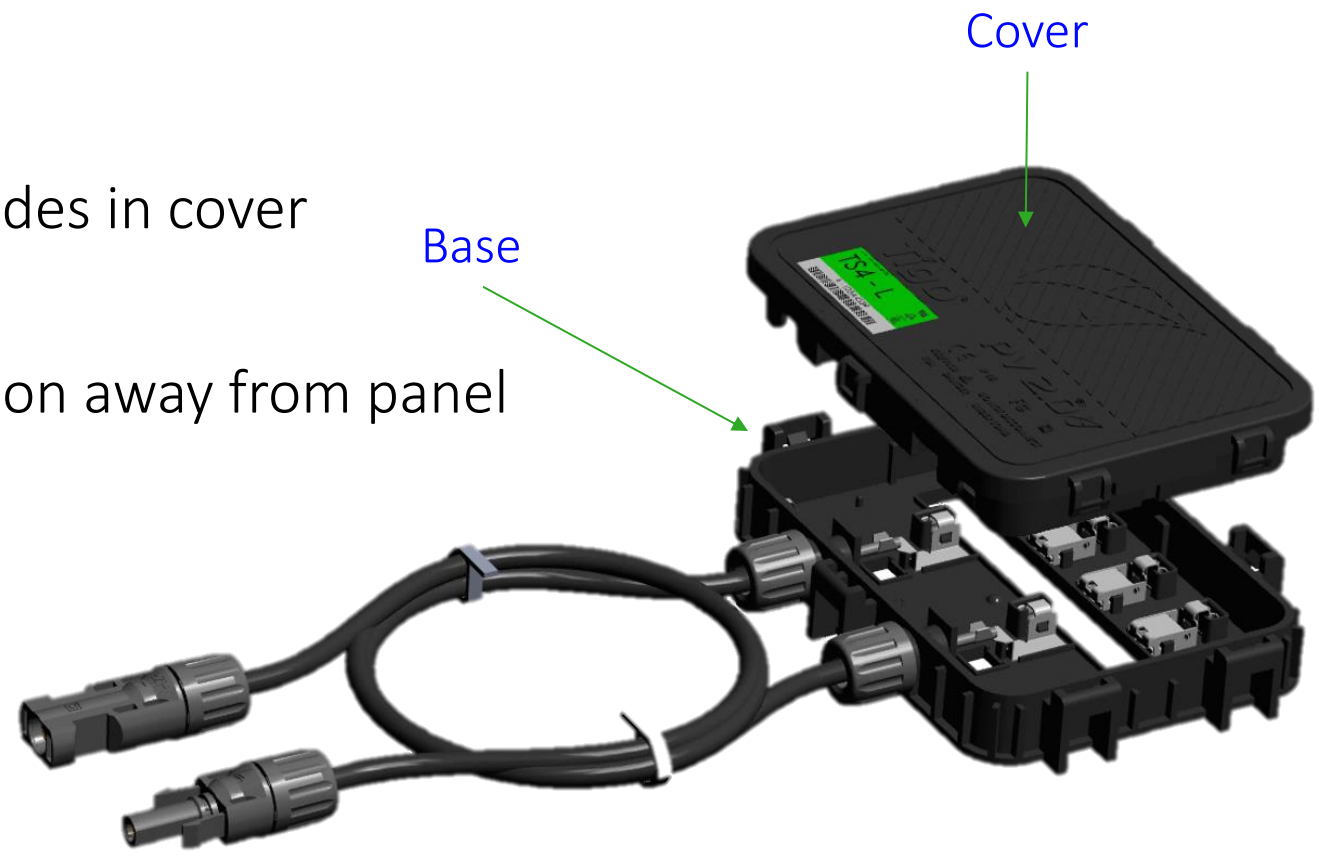
- ✓ Modularity
- ✓ Selective deployment
- ✓ Predictive IV (PIV)

Lowest cost → Greatest ROI

PV 2.0

TS4: Universal Modular Platform for EVERY PV Module

- Designed to easily facilitate any PV Module functionality
- Electronics in cover
  - Simple plug and play
  - All needed functions – even Diodes in cover
  - Easy to Upgrade
  - Highest reliability: heat dissipation away from panel



As simple as a USB or a Power Plug

The TS4 Covers

Select The Functionality that Best Addresses Your Needs

Diodes
TS4-D

Monitoring
TS4-M

Safety
TS4-S

Optimization
TS4-O

Long Strings
TS4-L

- Start with a TS4 “dumb” PV Module, convert any to a Smart Module as needed.
- Convert to a Safety (RSS), Optimization, Long String or just Monitoring at any point!
- Pay only for your needs, with the change of the cover

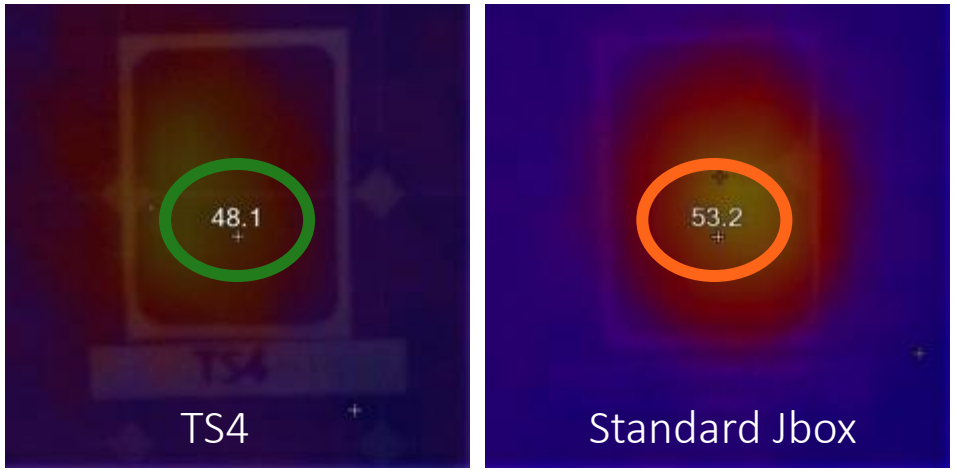
No more buying a full function Power Optimizer!!!!!

Diodes

Diodes

TS4-D

- Field replaceable
  - Bad diode? Replace a cover, not Module
- Most reliable
  - Best Performance
  - Heat dissipation away from the module
  - 5°C less with TS4-D if bypassing



MORE RELIABLE THAN A STANDARD JBOX!

Monitoring

Diodes | Monitoring

TS4-M

- Module level Monitoring
- Capable of measuring at 2 Sec increments
- Enhanced Operation & Management
- PV-2.0 data synchronization
- Module Bar code tracking
- Fleet management
- CRM integration
- Warranty tracking

Tigo

PV 2.0

Safety

Diodes | Monitoring | Safety

TS4-S

- NEC 690.12 rapid shutdown compliant
- Module-level deactivation
- Automatic or manual shutdown
- Over-voltage protection

- For Revenue protection, Remote Shutdown

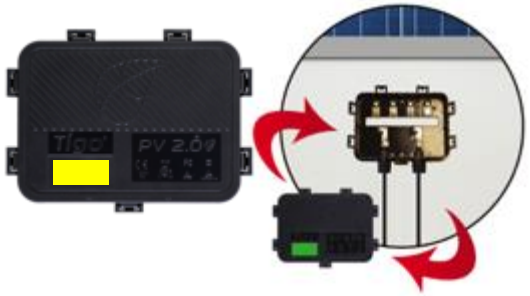
- Includes all the benefits of Monitoring

Tigo

PV 2.0

Optimization

Diodes | Monitoring | Safety | Optimization



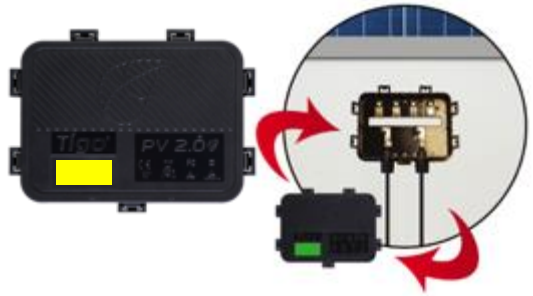
TS4-O

- Advanced energy harvesting
- Easiest design
- Shade and age tolerance
  - Can be used to mix old modules with new ones
  - Maximized roof usage
- Incorporating **Predictive IV** technology
- Includes all the benefits of Safety

Tigo

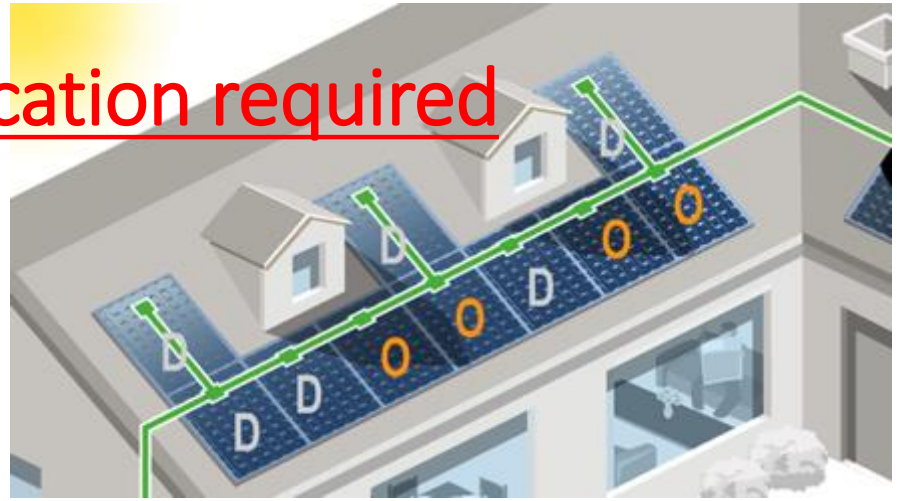
PV 2.0

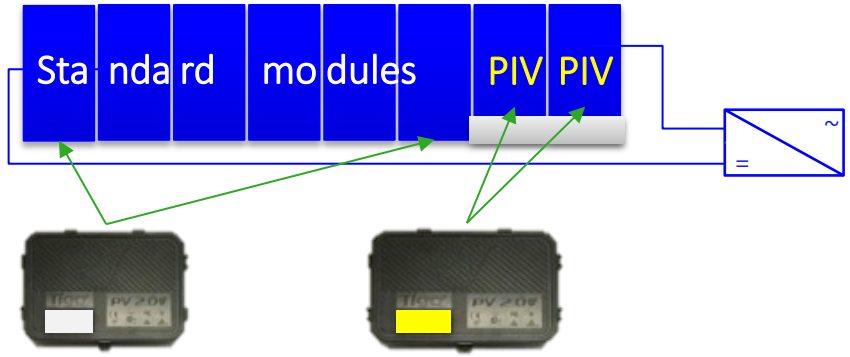
Optimization: Predictive IV (PIV)



is State-of-the-Art Optimization Technology

- Tracking algorithm utilizes module's unique parameters and advance analytics, incorporates:
  - MPPT
  - Impedance Matching techniques
  - Historical module and system behavior statistics
- PIV predicts the most optimum settings allowing each PV Module to generate the maximum energy
- No Communication required





TS4-D
Non-optimized

TS4-O
Predictive IV

Long Strings

TS4-L

Diodes | Monitoring | Safety | Optimization | Long strings

- The Problem
  - Maximum string length is determined by voltage
  - Maximum inverter power cannot be reached
- The Solution
  - Reducing the voltage of each panel, increases number of modules per string
  - With Tigo, string length increases by up to 30%
- The Benefits
  - Lower cost due to less components (combiners, conduits, wires, less time to install, etc.)
  - Faster installation
  - Greater design flexibility
  - Lower wire-losses
- Includes all the benefits of Optimization and Safety

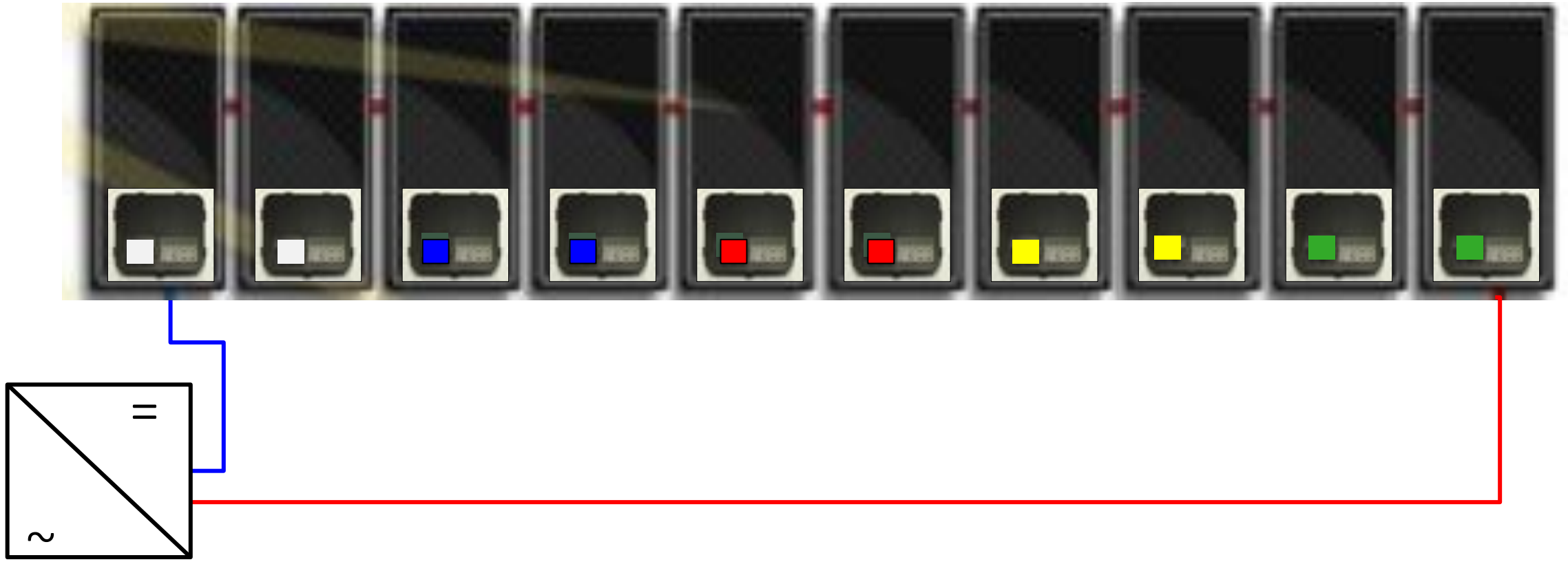
Did you think this is ALL?

Only 3 Modules are shaded,
in need for optimization

SELECTIVE DEPLOYMENT

TS4 – Selective Deployment

Selectively Deploy According to your needs



Design Guidelines

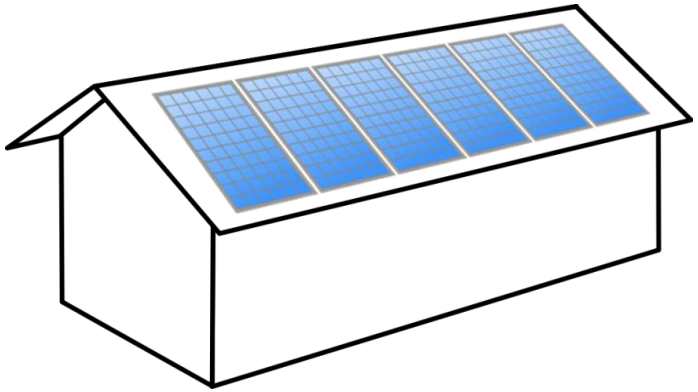
Modularity and Selective Deployment

Step 1: Select the Basic Functionality that Addresses your Needs

Is Rapid Shutdown/module level disconnect required? – Click Yes or No

Yes

No



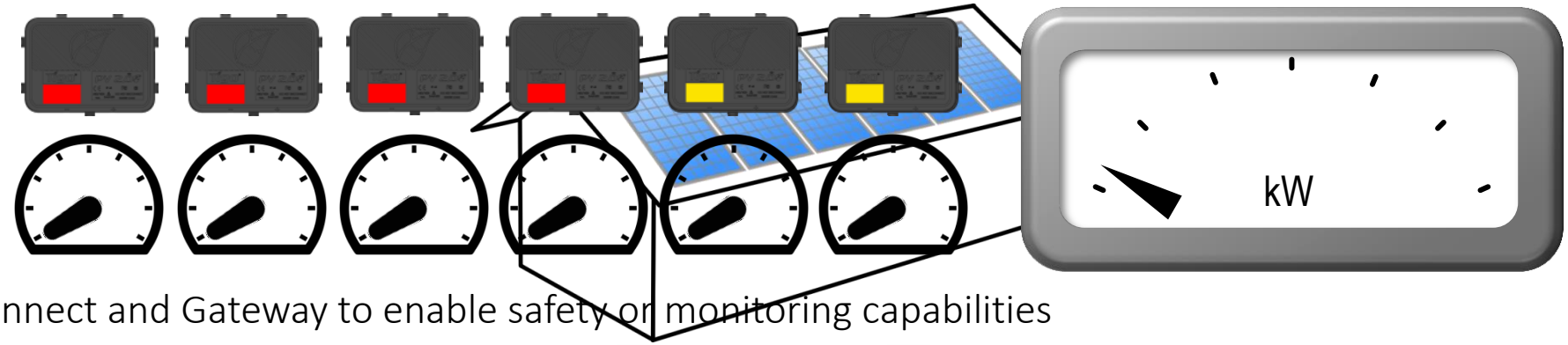
Modularity and Selective Deployment

Step 1: Identify the Basic Functionality That Addresses Your Needs

TS4-S x 6

TS4-O x 2

Without optimization, any shaded module affects the whole string. Selective deployment of optimization on only the shaded modules improves performance for unshaded modules.



Use Cloud Connect and Gateway to enable safety or monitoring capabilities

Click here to continue

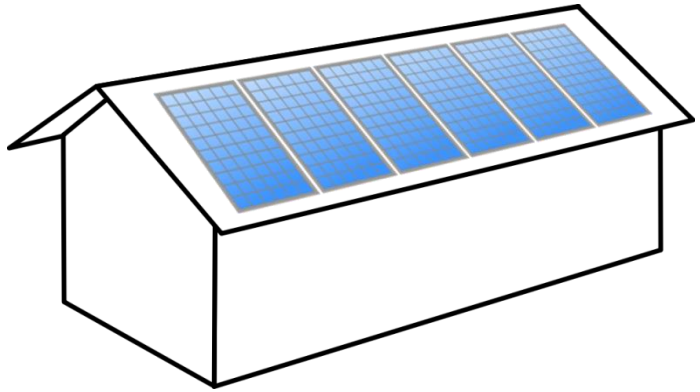
Modularity and Selective Deployment

Step 1: Select the Basic Functionality that Addresses your Needs

Would you like to have monitoring? – Click Yes or No

Yes

No
I'm on a tight budget this time



Modularity and Selective Deployment

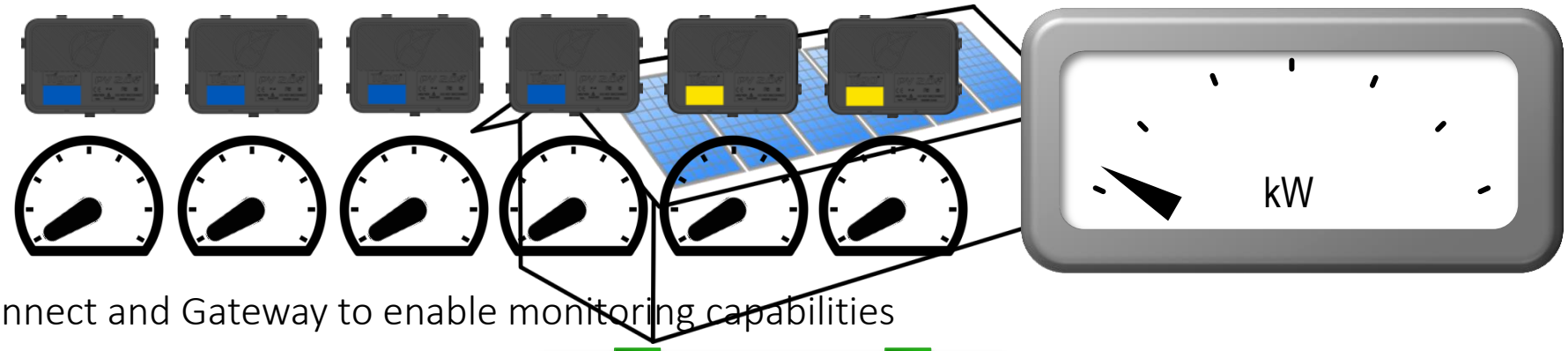
Step 1: Identify the Basic Functionality That Addresses Your Needs

Step 2: Select the Additional Functionality to Optimize Your Needs

TS4-M x 6

TS4-O x 2

Without optimization, any shaded module affects the whole string. Selective deployment of optimization on only the shaded modules improves performance for unshaded modules.



Use Cloud Connect and Gateway to enable monitoring capabilities

Click here to continue

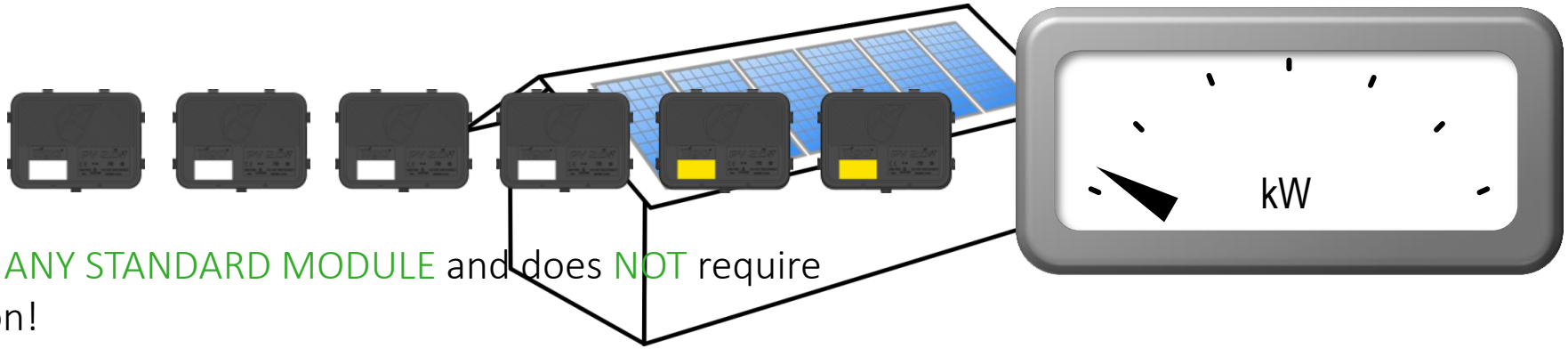
Modularity and Selective Deployment

Step 1: Identify the Basic Functionality that Addresses Your Needs

TS4-D x 6

TS4-O x 2

Without optimization, any shaded module affects the whole string. Selective deployment of optimization on only the shaded modules improves performance for unshaded modules.



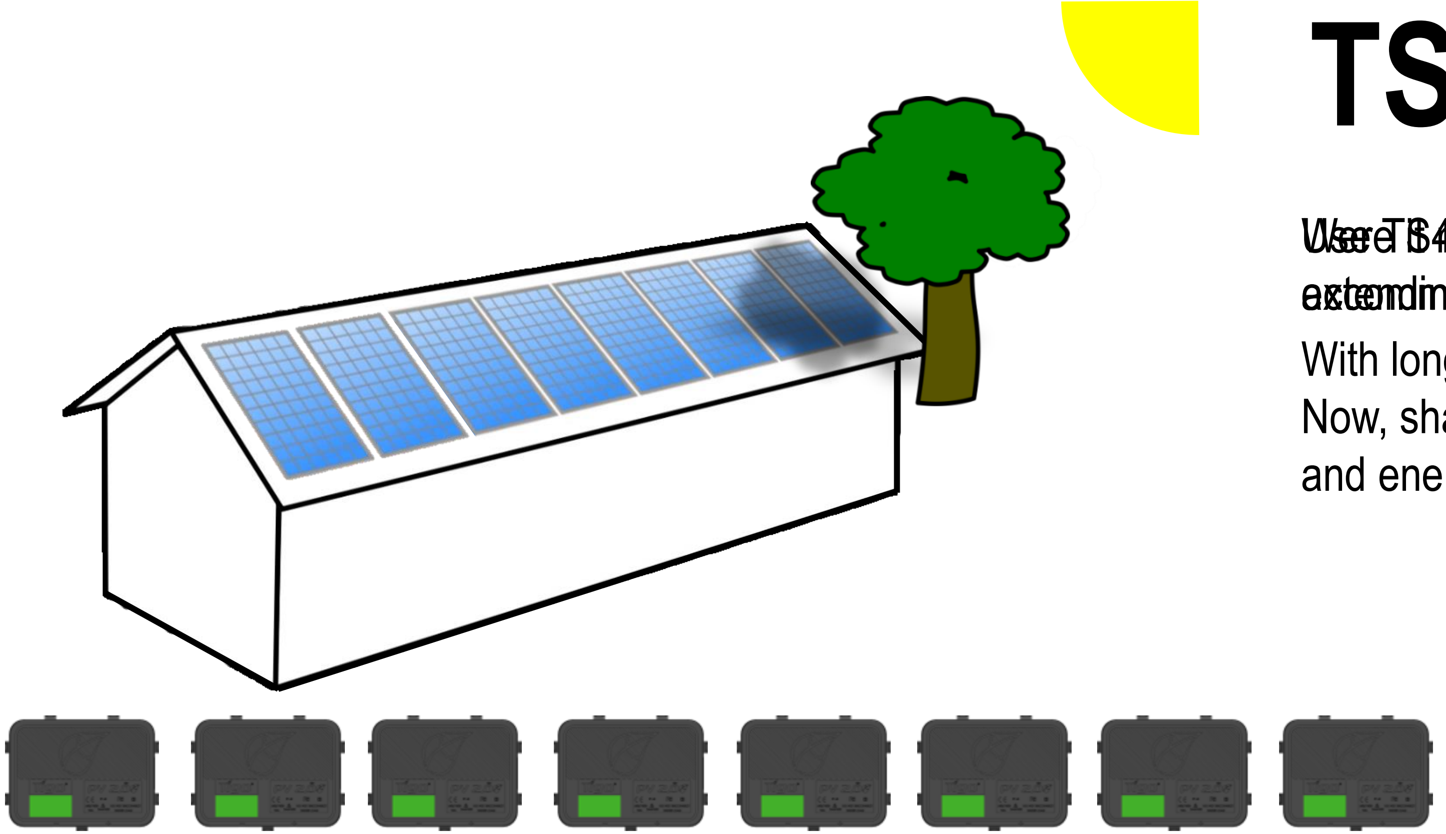
Applicable for ANY STANDARD MODULE and does NOT require communication!

Click here to continue

Modularity and Selective Deployment

Step 2: Identify shaded areas and optimize utilizing PV

Step 3: Is the design satisfying system needs

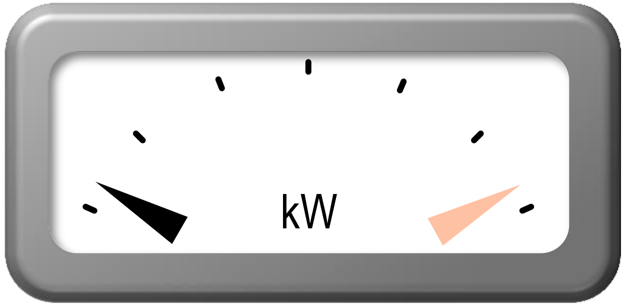


TS4-L x 8

Were there voltage limitations, could it accommodate more modules?

Use TS4-L to maximize potential by extending the string length

With longer string you also get built-in optimization. Now, shaded module doesn't affect the whole string and energy gain is maximal



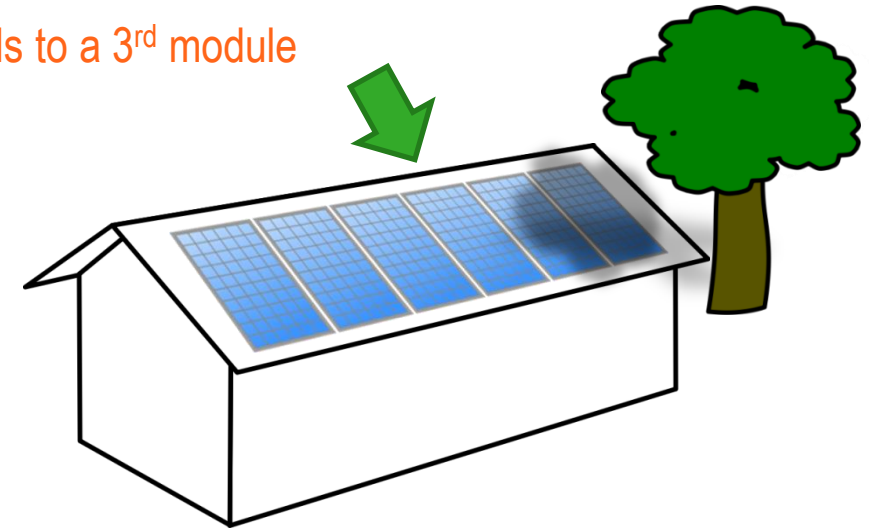
Without optimization, energy loss is 60% to 70% higher

Applicable for ANY STANDARD MODULE and does NOT require communication! Use Cloud Connect and Gateway only if safety or monitoring capabilities are required

Click to continue

Last but not Least - Upgrade As Your Needs Change

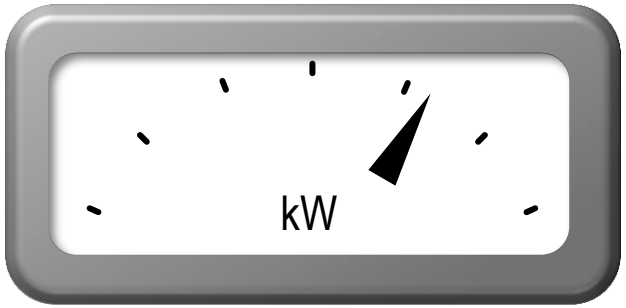
TS4 gives you the ability to easily change cover conditions



TS4-D x 3

TS4-O x 2

Without optimization, any shaded module affects the whole string. In this scenario, a non-optimized module is shaded and affects the whole string until the cover is replaced



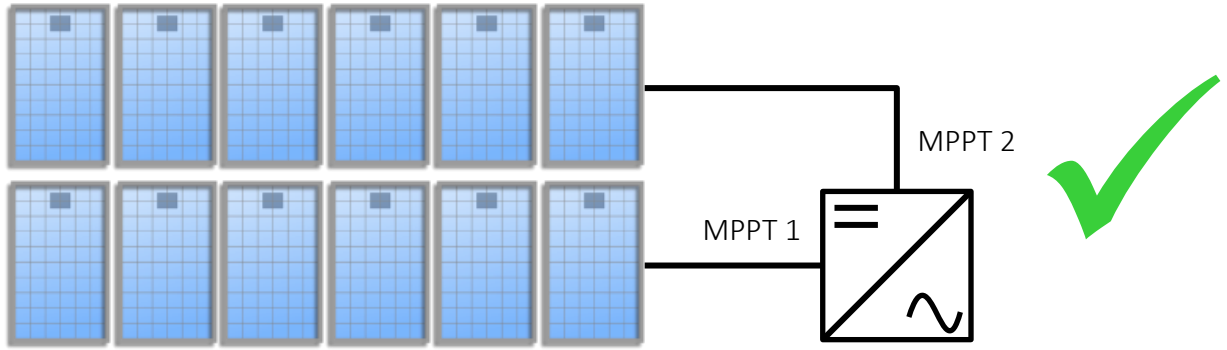
TS4 covers can be UPGRADED to solve changes to site conditions

Click to continue

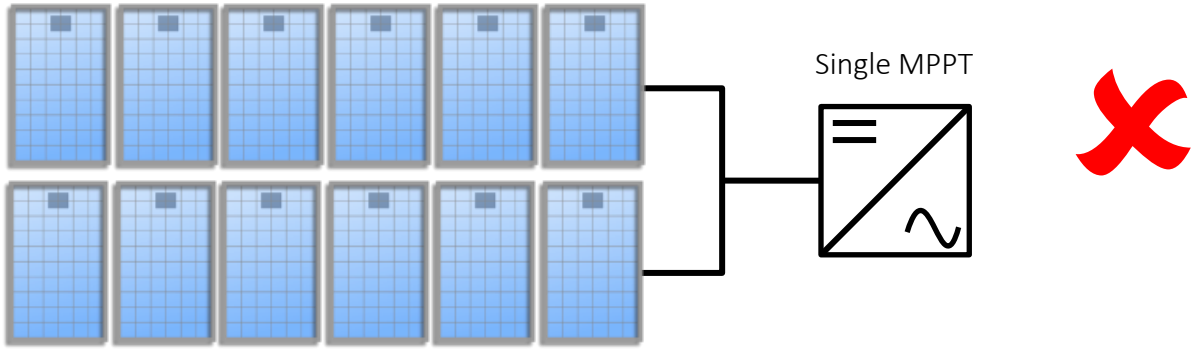
To Sum up

Partial Optimization

- Selective deployment of optimization is intended for systems with a <u>single string per MPPT.</u>



- Use full optimization on parallel strings connected to the same MPPT.



To Sum up

Commercial Systems

Place anywhere:

Diodes

Monitoring

Place on <u>all</u> modules on same MPPT:

Safety

Optimization

Longer Strings

Communication Accessories

Required only for Monitoring and/or Safety purposes

1 TS4 Smart Module

Power management and communication

2 Gateway

Transmits data to Cloud Connect

3 Cloud Connect

Communication hub to the cloud

Tigo

PV 2.0

Tigo Cloud Eco-System Solution

Power management, ERP, Process control, Load Balancing, Billing, ...

3rd parties devices monitoring

Cloud Data Center

Module Level Monitoring & Fleet Management

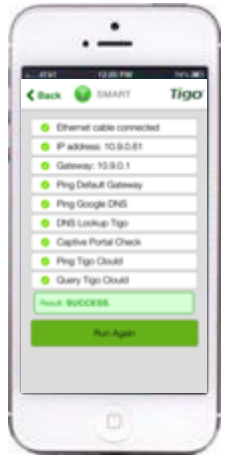
Module Level Monitoring

API Access

Wi-Fi or Ethernet

Visibility, transparency, disconnect – intelligence at the module level

Configuration and SMART On Site Commissioning

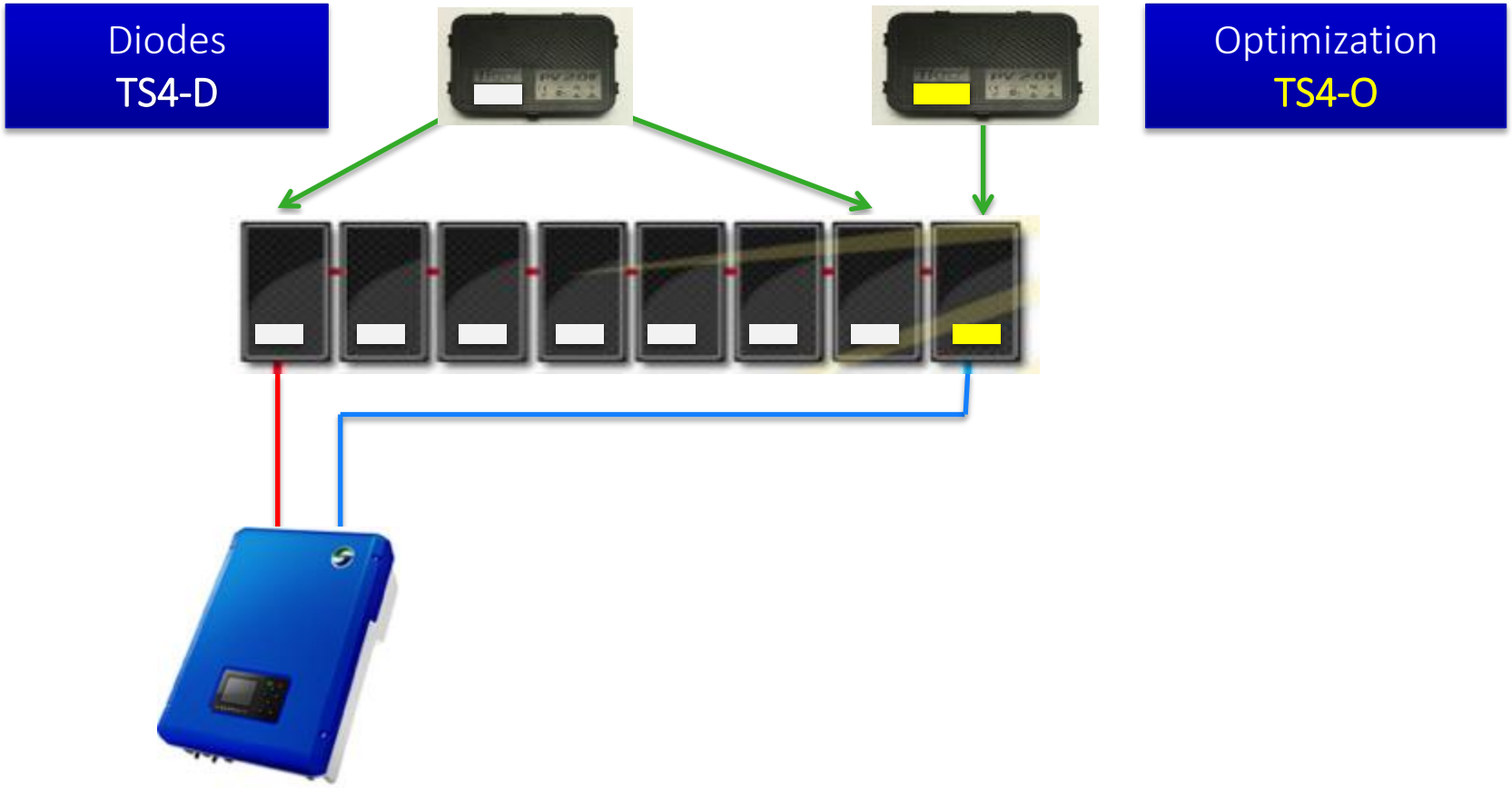


Smart Modules

External Module Level Shut Down Mushroom Button

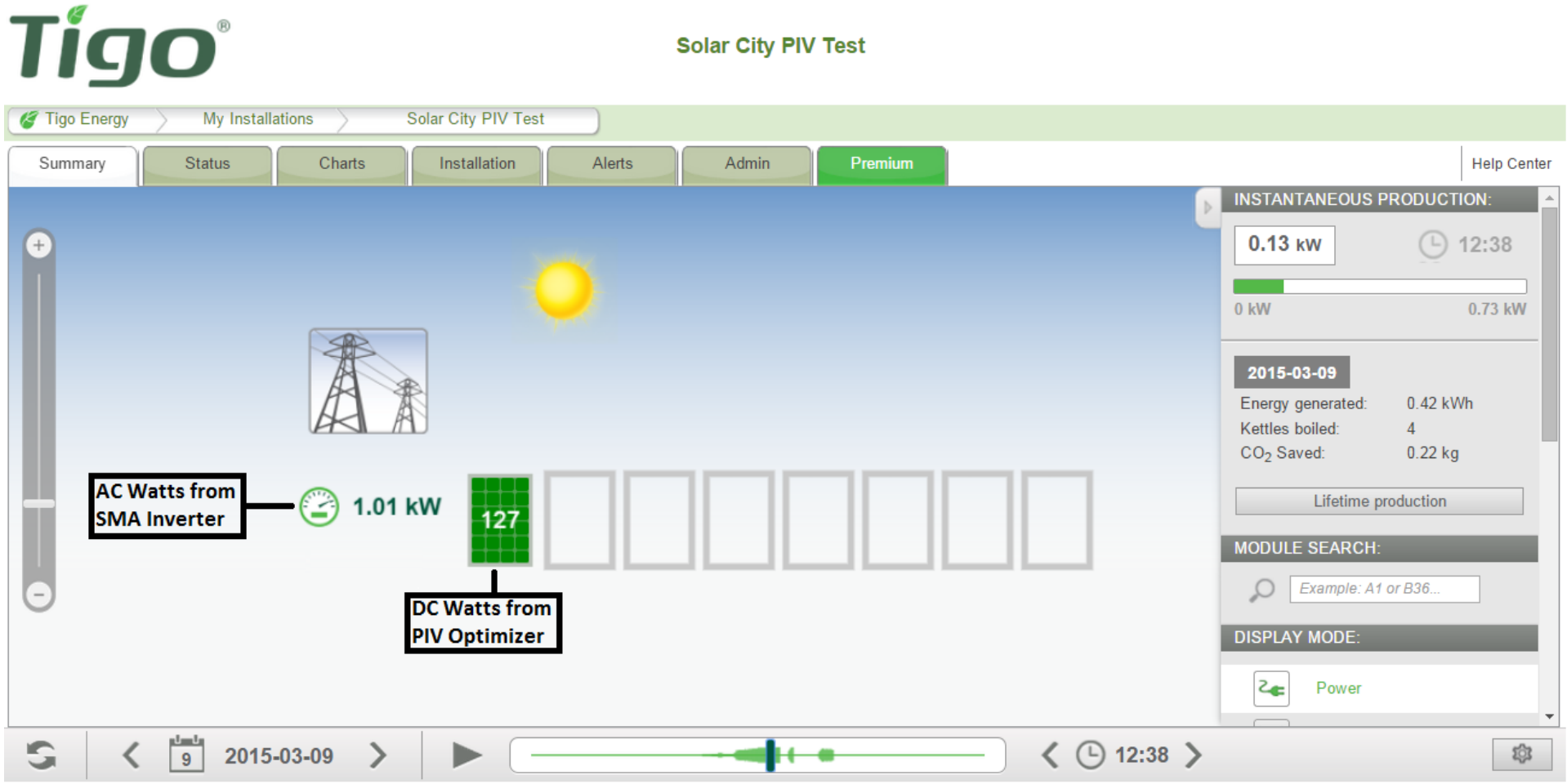
Selective Deployment Test Results

Selective Deployment – Test



Selective Deployment – Equipment / Setup

Selective Deployment – Monitoring



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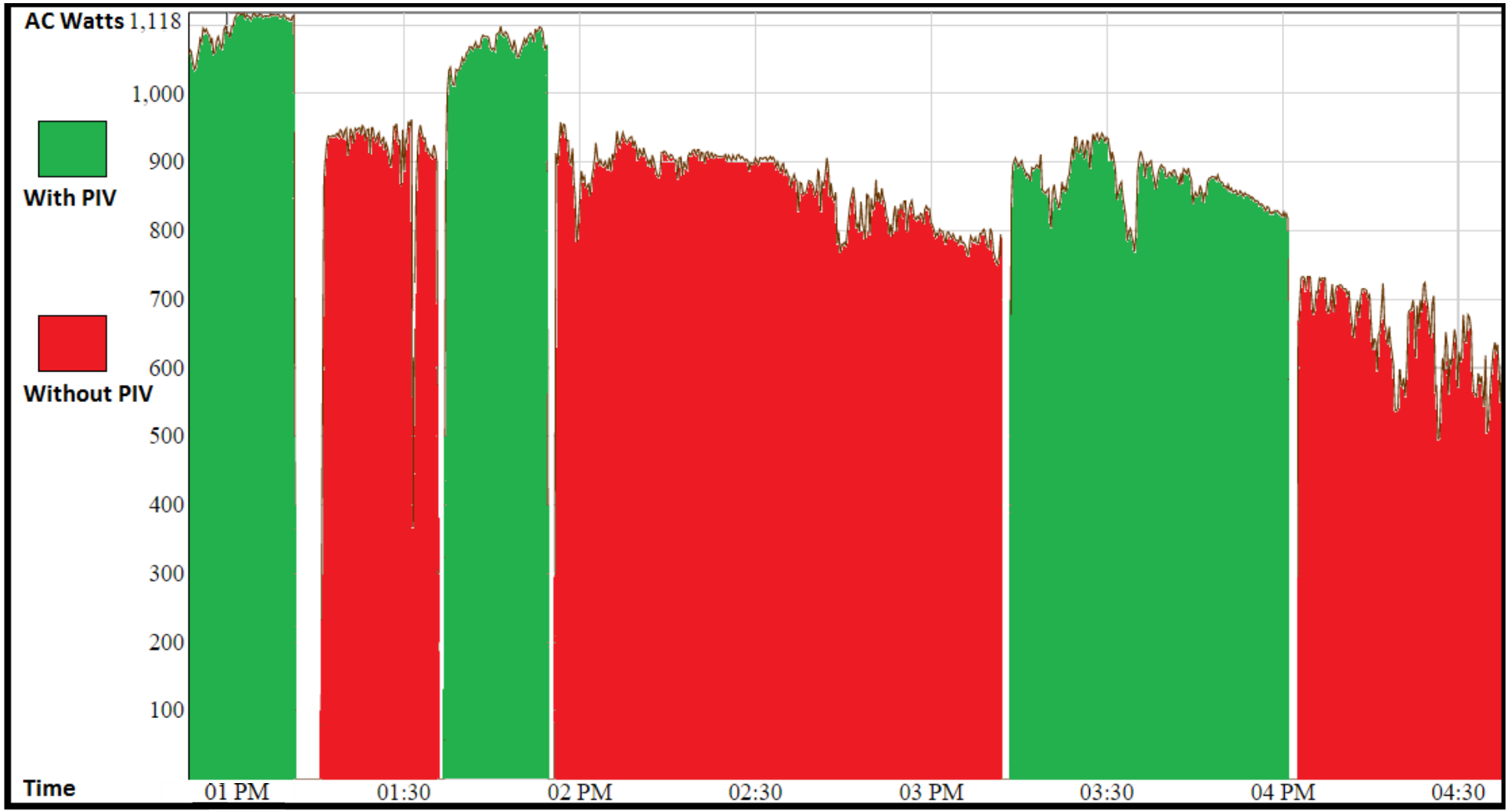
PV 2.0

Selective Deployment – Results



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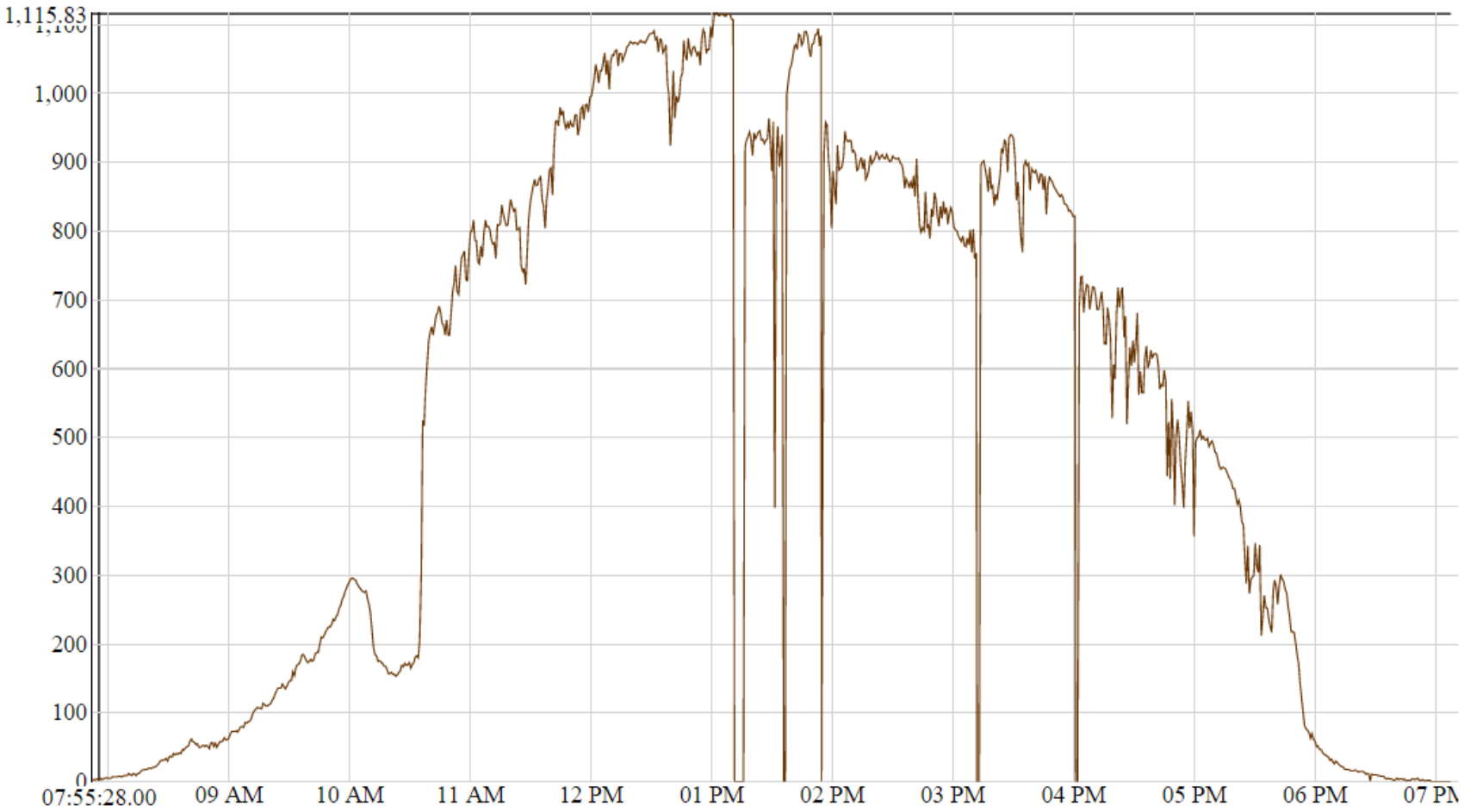
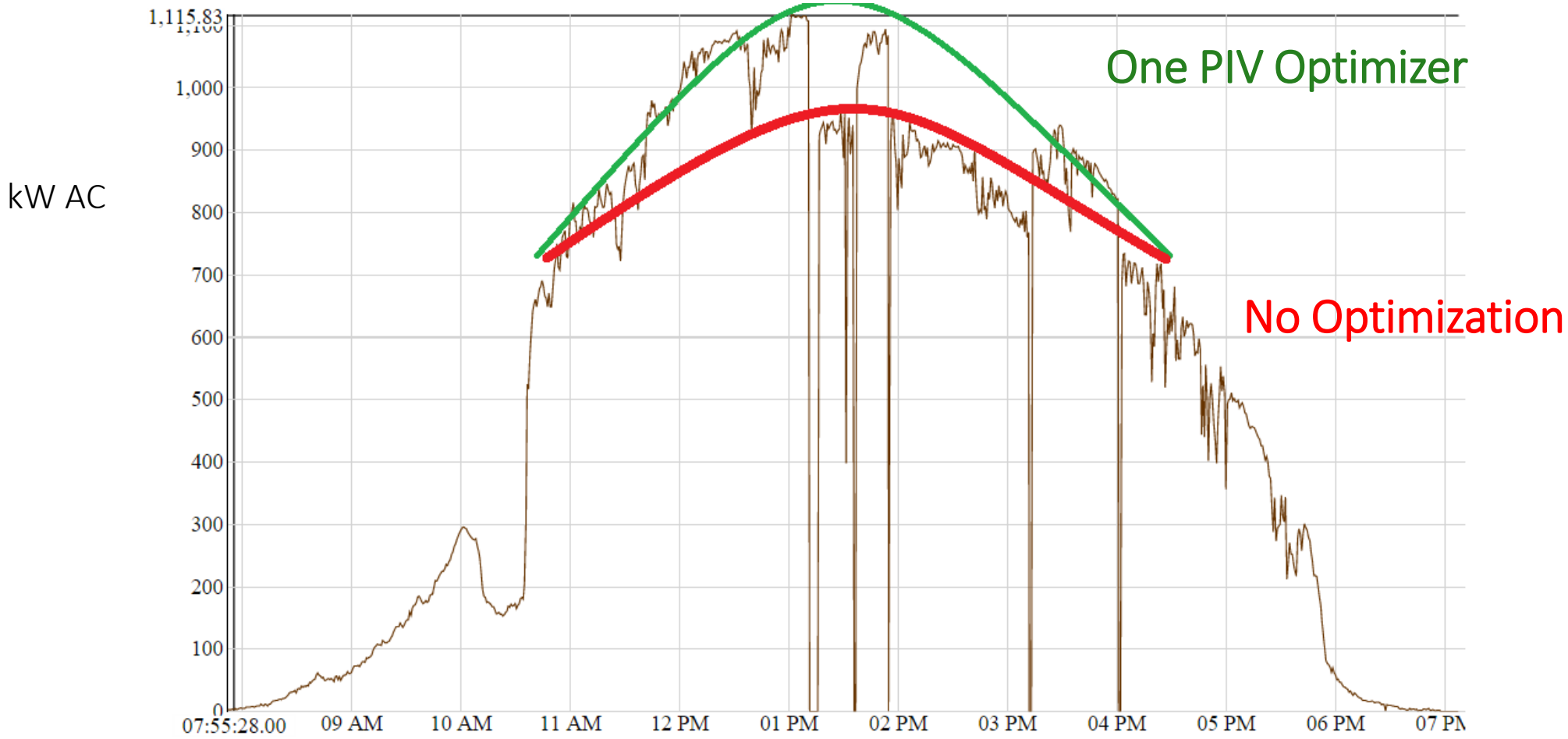
PV 2.0

Selective Deployment – Raw Inverter AC Power Curve

kW AC



Selective Deployment – Projected Power Curve Loss



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Selective Deployment – Conclusion

- A single optimizer Selectively placed on shaded module, recovered 18.5% Energy
- The PIV based optimizer used demonstrated communication less operation
- Applicable to ANY module on a single string!

The TS4 Platform - Summary

TS4 - 3 points to remember

Modularity

5 different functional covers available

Selective Deployment

Any mix of the covers in one string

Predictive IV (PIV)

Optimization with **NO** communication

TS4 Platform Partners – Beyond ONE

- Every customer is unique, every project is different
- Adapt the PV Module as needed

- Different cover functionalities @ Different price points
- Standard universal P&P platform for every PV module
- Start with a base Smart PV Module and upgrade when needed

HAVE THE FLEXIBILITY TO CHANGE FUNCTIONALITY TOMORROW

Tigo

Thank you