Panel Level Power Electronics - From vision to commercial reality.

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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

- Fronius IG
  - 1 kW – 6 kW
- Fronius IG Plus
  - 4 kW – 12 kW
- Fronius IG Central
  - 30 kW – 50 kW
- 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:
- Unshaded: No obstructions
- Horizontal: Flat shade object placed across four modules, with height of approx. 1 cell
- Pole: 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
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.

- **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.

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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 planned, 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 Chinese 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 their 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 their systems were working.
Outline

• Insiders view on DC Power Electronics
  3. Commercial reality (Bankability)
Tigo Components

Smart Module:
- Tigo Maximizer technology built into a PV module to become a Smart Module
Benefits of Distributed Electronics?

- Design Flexibility
- More Energy
- Enhanced Safety
- Active Management

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• **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.
• bank·a·ble (bǎŋˈkə-bəl) adj.
  • 1. Acceptable to or at a bank: bankable funds.
  • 2. Guaranteed to bring profit
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.
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**

### Benefits
- Programmed at factory
- Not temperature dependent
- 30% longer strings
- 30% lower I2R losses
- Fewer BOS components
- More efficient inverters

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

### String Length

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<th>72-Cell</th>
<th>Smart Curve</th>
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<td>36.1</td>
<td>36.1</td>
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<tr>
<td>Voc</td>
<td>37.3</td>
<td>31.5</td>
<td>44.9</td>
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### Electrical Specifications
- Max Voltage
- Certification
- String Length
- Fill Factor
- Certification:
  - UL1741, EN62109-1
  - TUV, CSA spec approved
  - Compliant with IEC and NEC
Example:
- Commercial roof
- 1,803 panels
- 400kW system
- 6 MMUs
- 22 Gateways
- Gateways spaced around obstructions

Each panel has a corresponding number and the PV strings are drawn as well.

Tigo Map Example
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

System is operating without issue
All 20 panels in the string have stopped producing power. A 2kW instantaneous drop in production.

Zoom in to inspect the string closer.
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.
A site visit was made on this day and the open circuit issue was fixed. The DC string fuse had failed.
Breakdown of PV Failures

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

- Installation & Commissioning: 55%
- Communications: 12%
- Weather: 11%
- Inverter: 5%

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
What is new in OEM Smart Modules? TS4?
Tigo® Introduces TS4

✓ Modularity
✓ Selective deployment
✓ Predictive IV (PIV)

Lowest cost → Greatest ROI
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

- 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

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

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
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
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
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**
Long Strings

TS4-L

- 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?

SELECTIVE DEPLOYMENT

Only 3 Modules are shaded, in need for optimization
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: Select the Basic Functionality that Addresses your Needs

Step 2: Identify shaded areas and optimize utilizing PIV

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
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: Select the Basic Functionality that Addresses your Needs

Step 2: Identify shaded areas and optimize utilizing PIV on only the shaded modules to improve performance for unshaded modules.

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.
Modularity and Selective Deployment

**Step 2:** Identify shaded areas and optimize utilizing PIV

Applicable for **ANY STANDARD MODULE** and does **NOT** require communication!

**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.
Modularity and Selective Deployment

Step 3: Identify shaded areas as an optimization strategy

Step 2: Identify shaded areas and optimize utilizing PIV

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

TS4-L x 8

Without optimization, energy loss is 60% to 70% higher
Last but not Least - Upgrade As Your Needs Change

Adding optimization ability is easy as changing site conditions

Shade extends to a 3rd module

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.
To Sum up

Partial Optimization

• Selective deployment of optimization is intended for systems with a single string per MPPT.

• Use full optimization on parallel strings connected to the same MPPT.
To Sum up

Commercial Systems

Place anywhere:
- Diodes
- Monitoring

Place on all 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 Cloud Eco-System Solution

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

Module Level Monitoring & Fleet Management

Module Level Monitoring

Wi-Fi or Ethernet

Cloud Data Center

API Access

3rd parties devices monitoring

Visibility, transparency, disconnect – intelligence at the module level

External Module Level Shut Down Mushroom Button

Smart Modules

Smart Modules API Access

Configuration and SMART On Site Commissioning

Tigo Cloud Eco-System Solution

PV 2.0
Selective Deployment Test Results
Selective Deployment – Test
Selective Deployment – Equipment / Setup
Selective Deployment – Monitoring
Selective Deployment – Results

AC Watts: 1,118

With PIV

Without PIV

Time:
- 01 PM
- 01:30
- 02 PM
- 02:30
- 03 PM
- 03:30
- 04 PM
- 04:30
Selective Deployment – Raw Inverter AC Power Curve
Selective Deployment – Projected Power Curve Loss

One PIV Optimizer

No Optimization
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
Thank you