Separating myths from reality in PV inverter reliability

Or, How I learned to stop worrying and love the BOM

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What inverter manufacturers think of reliability - 2006, prior to Enphase

- Fronius, Head of Sales: “Inverter MTBF may reach 12 years by 2015. A 20-year lifetime can’t be achieved.”
- Mitsubishi: “A 20-plus-year life for inverters is impossible. Some parts of the inverters would need to be replaced over such an extended period.”
- SMA America, President: “Why focus on higher reliability? Our customers worry only about first-cost.”

Source: Navigant Consulting report to NREL on PV inverter status. NCI found that inverters were limited by 18 different topics. Technology though included electrolytic caps, switching transistors.

- eCaps = reliability limiting component!
Types of inverters

- ~600 V DC Bus
  - Current matched modules
  - Solar pv modules connected in series
  - String or central inverter
  - Electricity grid
- 240 VAC Bus
  - Voltage matched modules
  - micro-inverters
  - 120/240 V ac
  - 50/60 Hz
  - 120/240 V ac
  - 50/60 Hz
  - Electricity grid
What about microinverters?

- Enecsys website: “The elimination of the components known to have relatively poor reliability - electrolytic capacitors and opto-couplers – was critical to improving the lifetime and reliability of Enecsys solar micro inverters.”
- Enphase white paper: “[our] study has shown that electrolytic capacitors are not a significant point of failure for micro-inverter reliability.”
- From Gunther Portfolio article: “SMA agrees with microinverter market leader Enphase Energy on the controversial topic of electrolytic capacitors when used appropriately.”
- String inverter manufacturers find the reliability claims of microinverters dubious.
Does what affects string inverters affect microinverters?

- In 2006 NCI was commissioned to determine feasibility of DOE goal of $0.25/Watt for inverters by 2020.
  - They found it was highly unlikely
  - The DOE rewarded inverter manufacturers by making the goal $0.10/Watt.
- This is based upon a LCOE of 5 cents per kWh, so reliability is critical
- MTBF of Enphase microinverters: 330 years.
- Why is a component limiting one technology and not the other? Why can’t even microinverter companies agree on this?
Switch mode power and PWM

- The switch is an FET, with a pulse turning it on and off.
- The voltage output is dependent upon the pulse “on time”
- “Pulse width modulation” (PWM) can output a sine wave into an integrator
- The “inverter” stage steers the sine wave to positive & negative lobes.
The need for storage

- With any switchmode power supply power in is transferred out
- At zero crossings the input power is zero
- The peak power is twice the average value (approximately)
- But a PV module wants to stay at MPP.
- This induces a 120 Hz “ripple” that can only be solved with energy storage.
- To filter this the storage energy needed really requires electrolytics
Reliability predictor models

- **MIL-HDBK 217F**
  - Last updated in 1995
  - Does not take into account base lifetime

- **Telcordia SR332.2**
  - Updated in 2006
  - Does not take into account voltage or capacitance

We use a model empirically developed by Cornell-Dubilier from field data:

\[
\text{FITs} \sim N \left( \frac{V_a}{V_r} \right)^3 V_r C^{0.5}
\]

Strong dependence on ratio of applied voltage to rated voltage, and rather weak dependence on capacitance.

Commercial eCaps only rated to 630 V maximum

Common string voltages = 500-600 V
Simulated results

Telcordia plus field data models. Powertrain only.

FITs vs Temperature, 3 kW string inverter (left), microinverter (right)

At 75°C, String FITs = 800, microinverter FITs = 30

Microinverter requires more components, but more balanced.

3kW string inverter design (ST)  Microinverter design (Microchip)
Why would microinverter companies be electrolytic averse?

• Electrolytics gained a bad reputation a decade ago for failing on DC busses in small power supplies, monitors, and computer motherboards.
  – Became known as “The Capacitor Plague”
• However in almost all cases these failures were linked to a Taiwanese knock off with poor production QC.
• Lesson learned: buy from reputable companies!
Summary

• The known failures of string inverter DC bus ecaps fits well with the conventional wisdom of small power supplies
  – Contributing to the myth that ecaps are not reliable in general
• However mechanisms are different, string inverters apply too much voltage stress, small caps fail due to QC issues.
• No model incorporates ripple current in reliability – Research project
• Well made caps with overhead can be made very reliable and are applicable in microinverters.
• Microinverters have comparable reliability to strings for most medium installs, but single failure only eliminates one panel.