Separating myths from reality in PV inverter reliability

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

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SDLE Reliability workshop, CWRU

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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!

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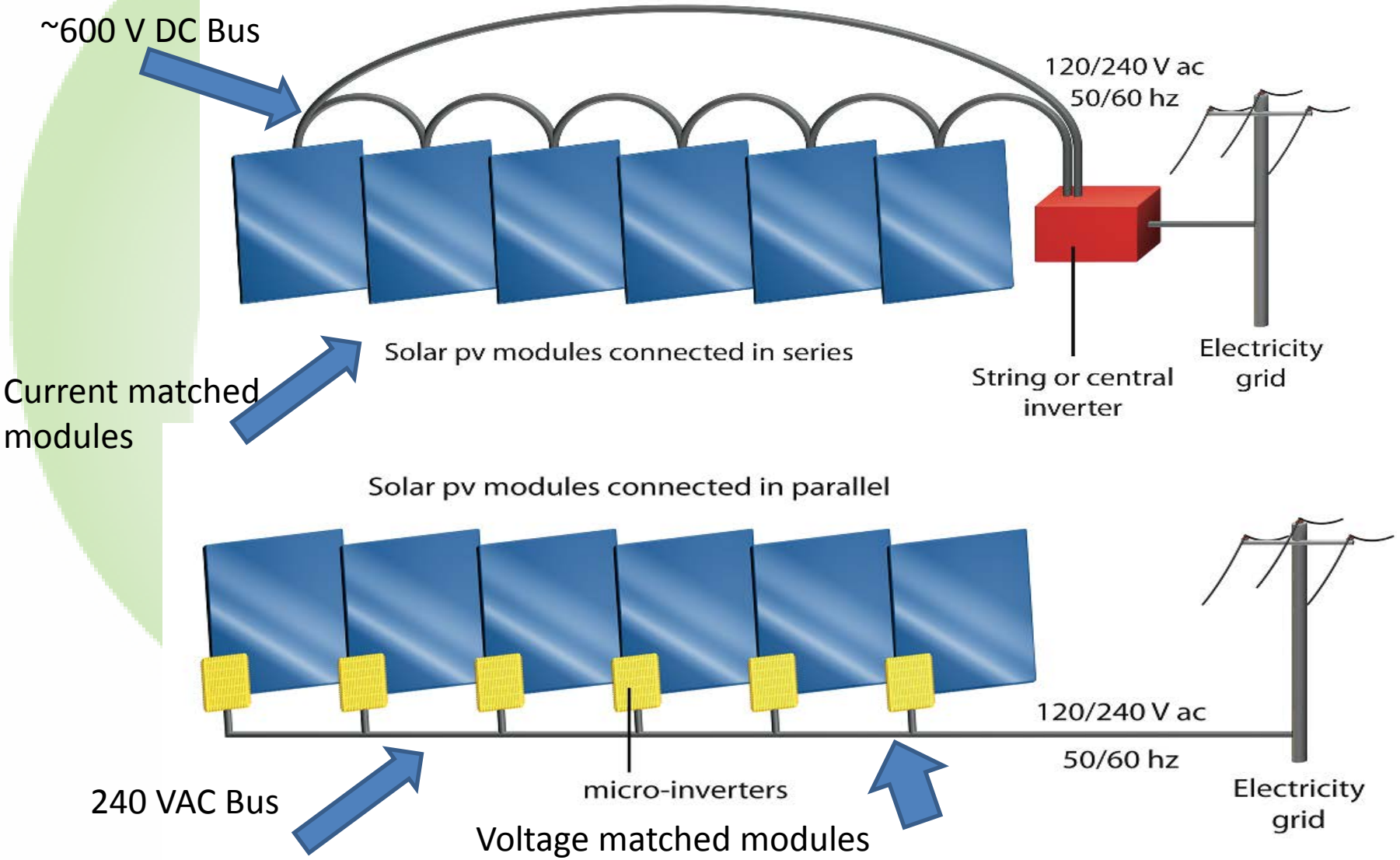
Types of inverters



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.

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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 string inverters in 2006: 5-10 years. In 2011: 15 years.
- 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?

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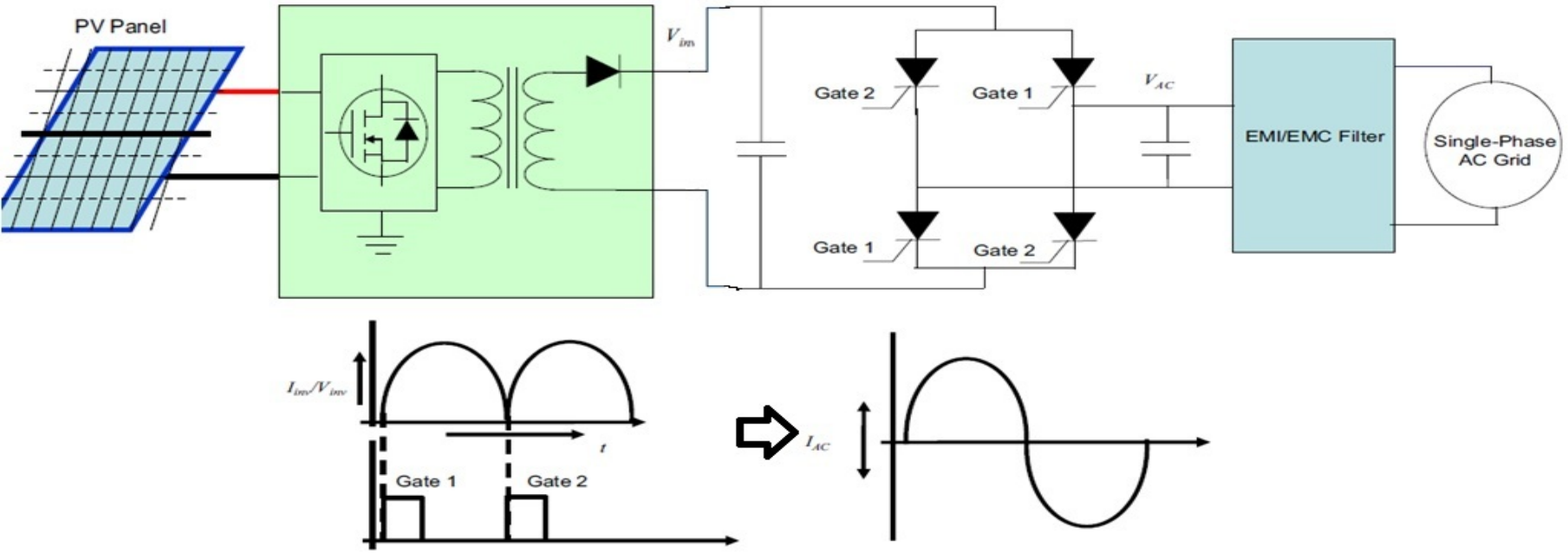
Switch mode power and PWM



- 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

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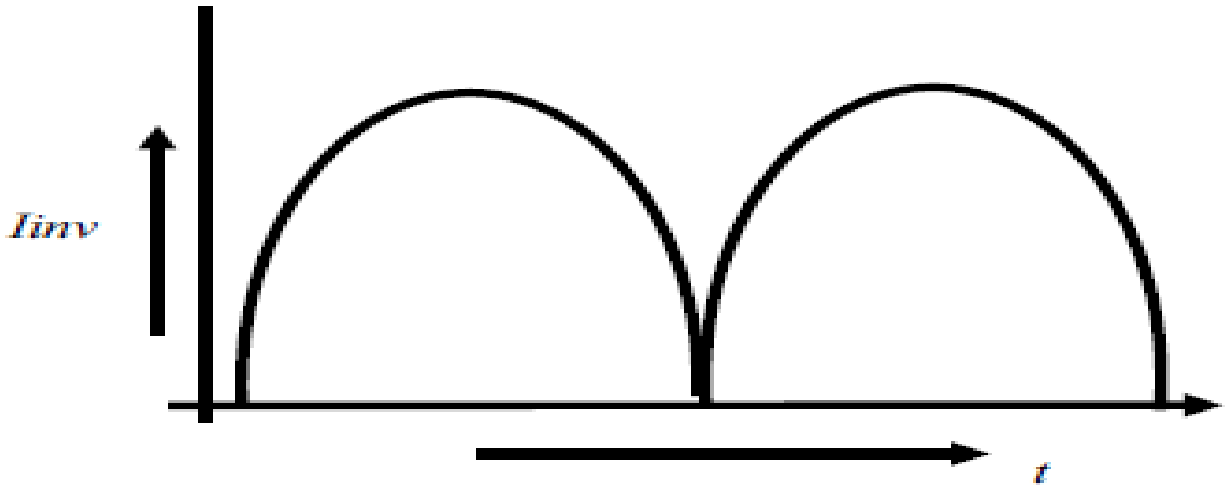
The need for storage

- 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



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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:

$$\mathbf{FITs \sim N (Va/Vr)^3 Vr\ C^{0.5}}$$

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

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Simulated results

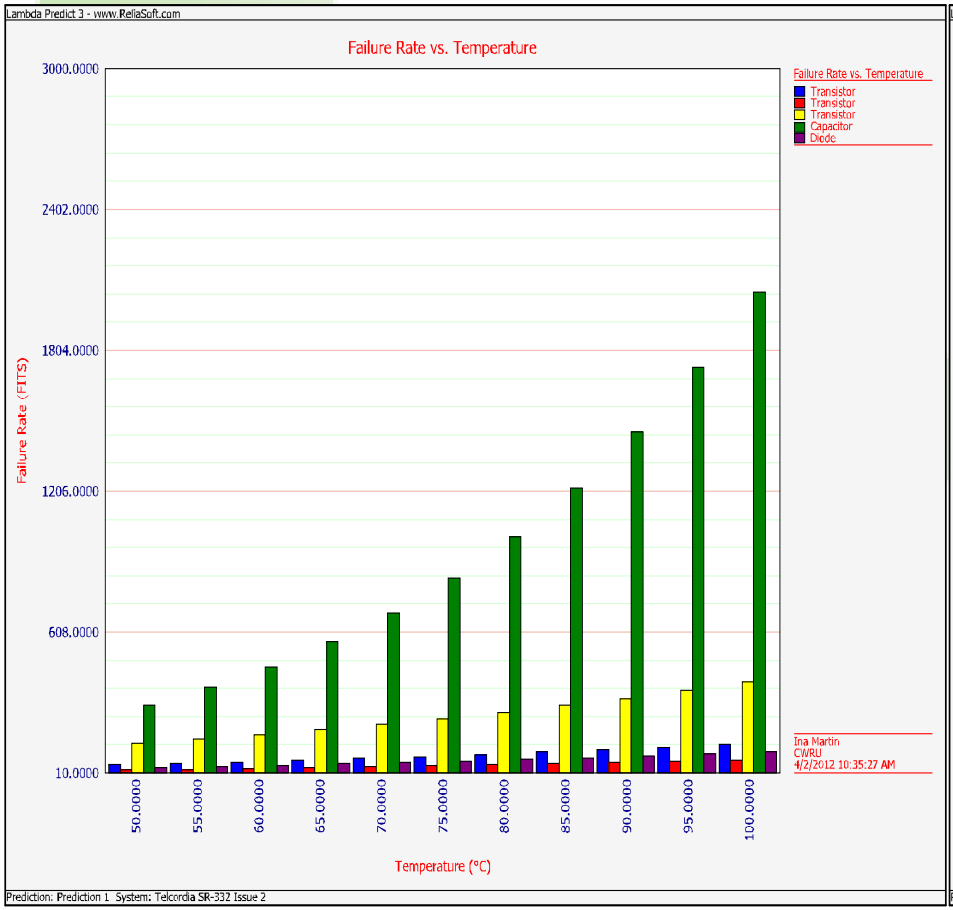
Telcordia plus field data models. Powertrain only.

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

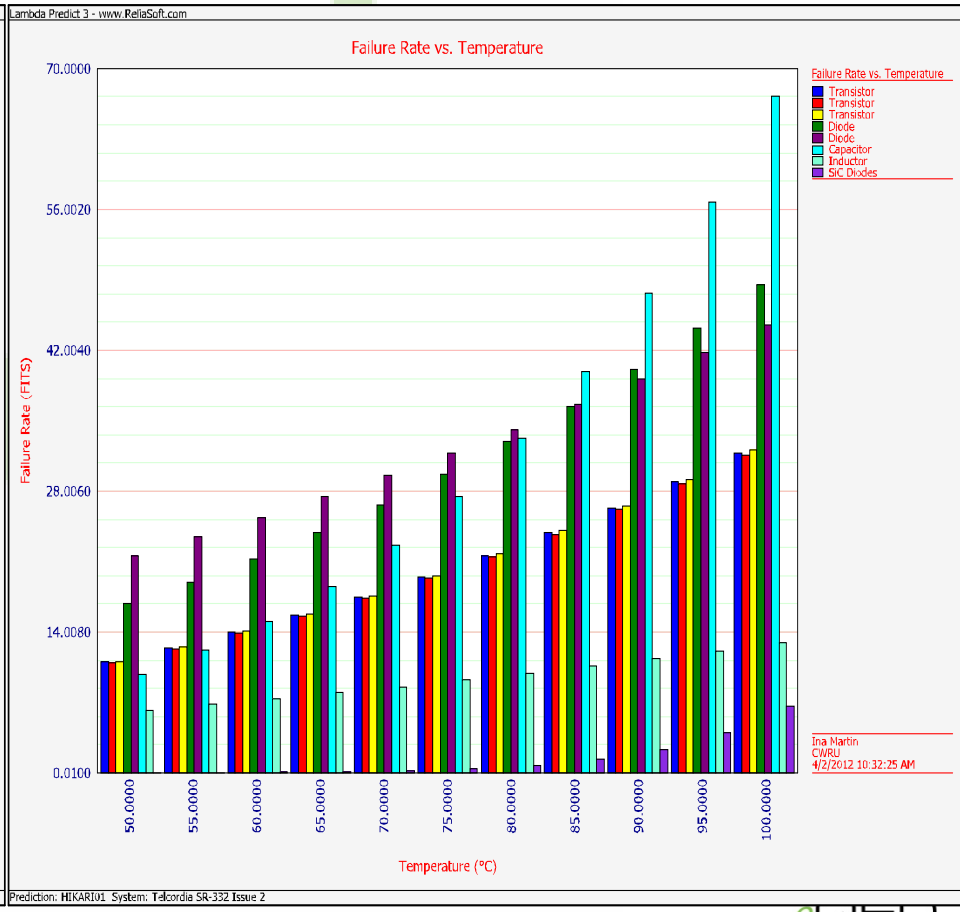
At 75 C, String FITs = 800, microinverter FITs = 30

Microinverter requires more components, but more balanced.

3kW string inverter design (ST)

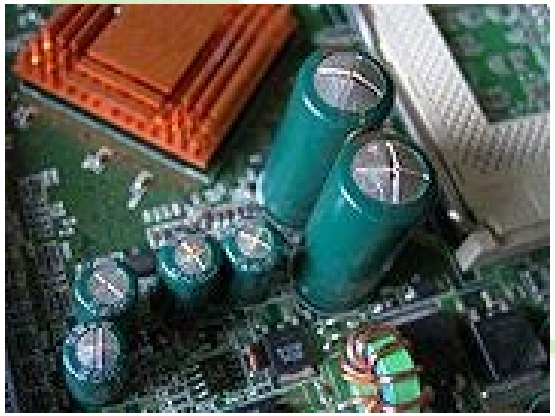


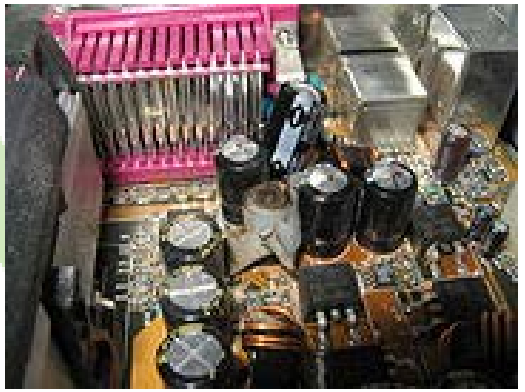
Microinverter design (Microchip)



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!





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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.

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