Module level power electronics:
Taking commodity components and making them last.
Reliability is linked with design, but is good design linked to reliability?

Tim Peshek
CWRU - SDLE

Intro and scope of talk

- **Question: Can we make a platinum level inverter, money is no object, and guarantee great performance and longevity?**
- **What is bad reliability vs prudent design?**
- **What's under the hood of an MLPE?**
- **How is reliability engineering done now?**
- **If you're so smart, what's your alternative?**

The solar energy marketplace intimately intertwines money and performance. But not in the right way!

Good design is:

"The best for the most for the least"

Charles Eames

$4500? Really, Chuck?

Poor design vs Reliability

- What differentiates poor design from reliability?
- What are the underlying assumptions in a Telcordia-style analysis?
- Where do these assumptions break down?

Example: Increase inverter power without changing mechanical housing, or magnetics. Now, at high noon, the inverters fail with a DC short.

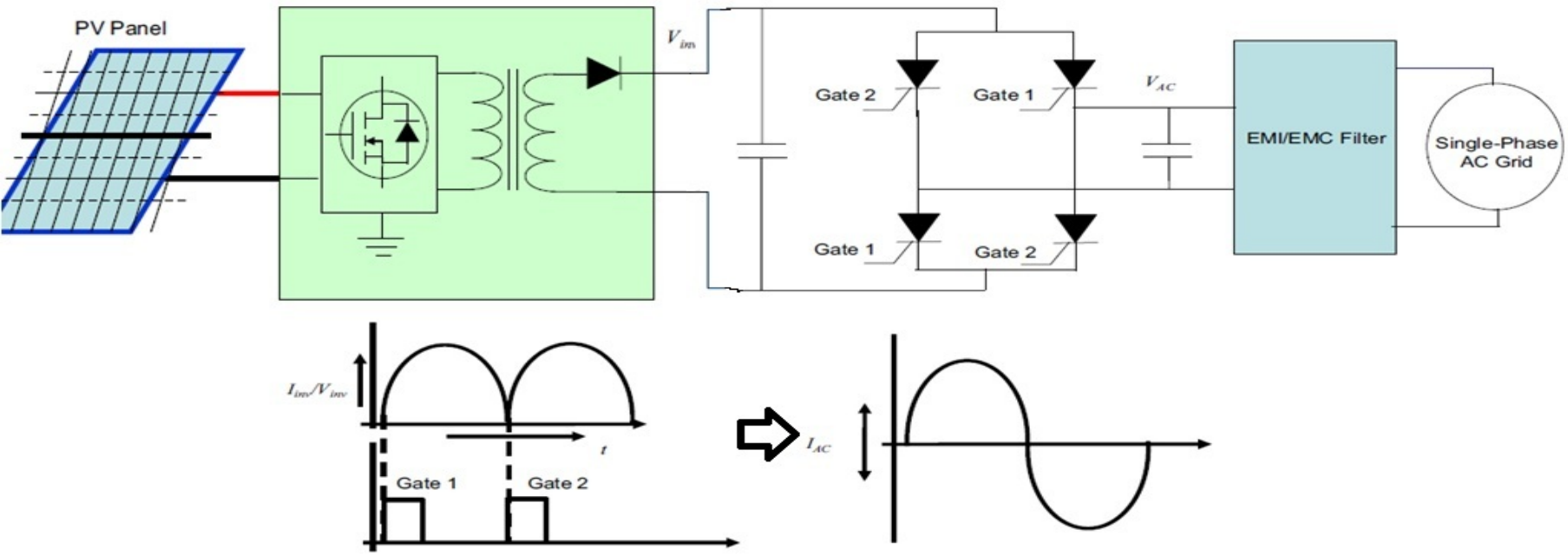
You wouldn't say that MTBF is reduced from 300 years to 300 minutes

FMEA: Saturation of core, leads to MOSFET avalanche from leakage inductance current spike.

Fix: Higher blocking voltage MOSFET, Or is it?

Higher V MOSFET = higher Rdson = greater dissipation = overheating.

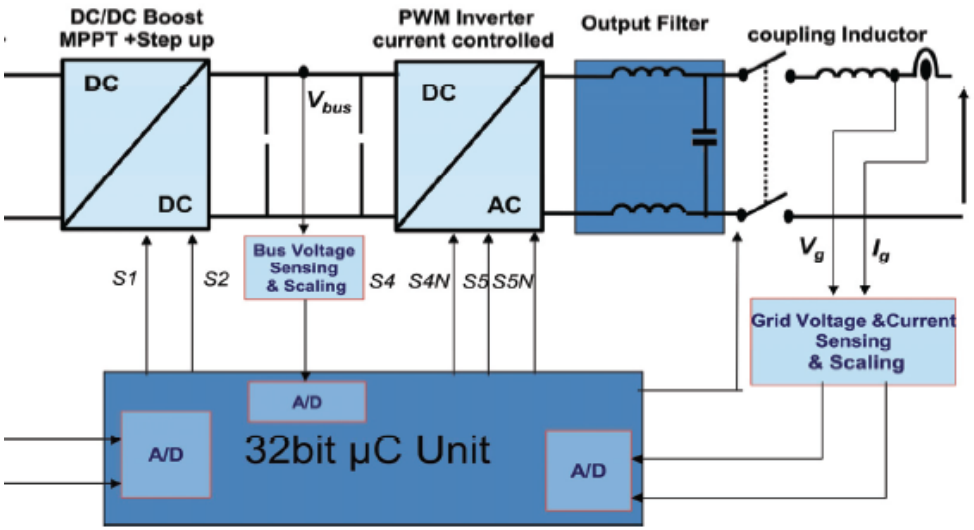
Single Stage Topologies

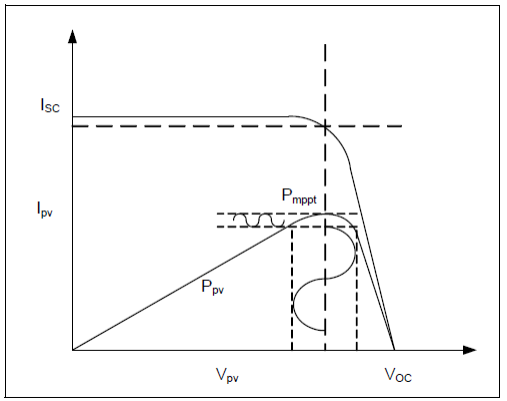


Single stage is implemented using a converter that contains zero in its transfer function.
Requires the use of electrolytic capacitors.
<u>No power factor correction</u>

2 stage topologies

"Wait, you *don't* want use e-caps?"
In that case you need an internal high voltage DC link.





$$C_{bulk} = \frac{P_{MPP}}{2\pi \cdot f_{ripple} \cdot V_{mpp} \cdot V_{ripple}}$$

You could use boost, but you're at (1/1-D) = 12, D > 91%!
stressful on components

Half Bridge or push pull would be nice too, with soft switching,
but the bulky transformers are less than ideal

Flyback at constant output voltage (HIGH!) can operate at moderate duty,
and in boundary conduction mode, with soft switching.

DC Optimizers

- Don’t need DC/AC, don’t need isolation, simpler topologies
- output is close to input = high efficiency!
- What’s not to love?
- But… you still need a string inverter, so the value proposition is more energy harvest from per module MPPT.

Is it a reliability gain? Probably not
unless they perform HV boost, removing a stage from string inverter, and isolation. But This starts getting away from residential-friendly.
HV boost = parallel modules, might as well go microinverter.

Unless everything is in the module. Good luck. We end up with IEC 61215 tests for inverters. Not a good idea.

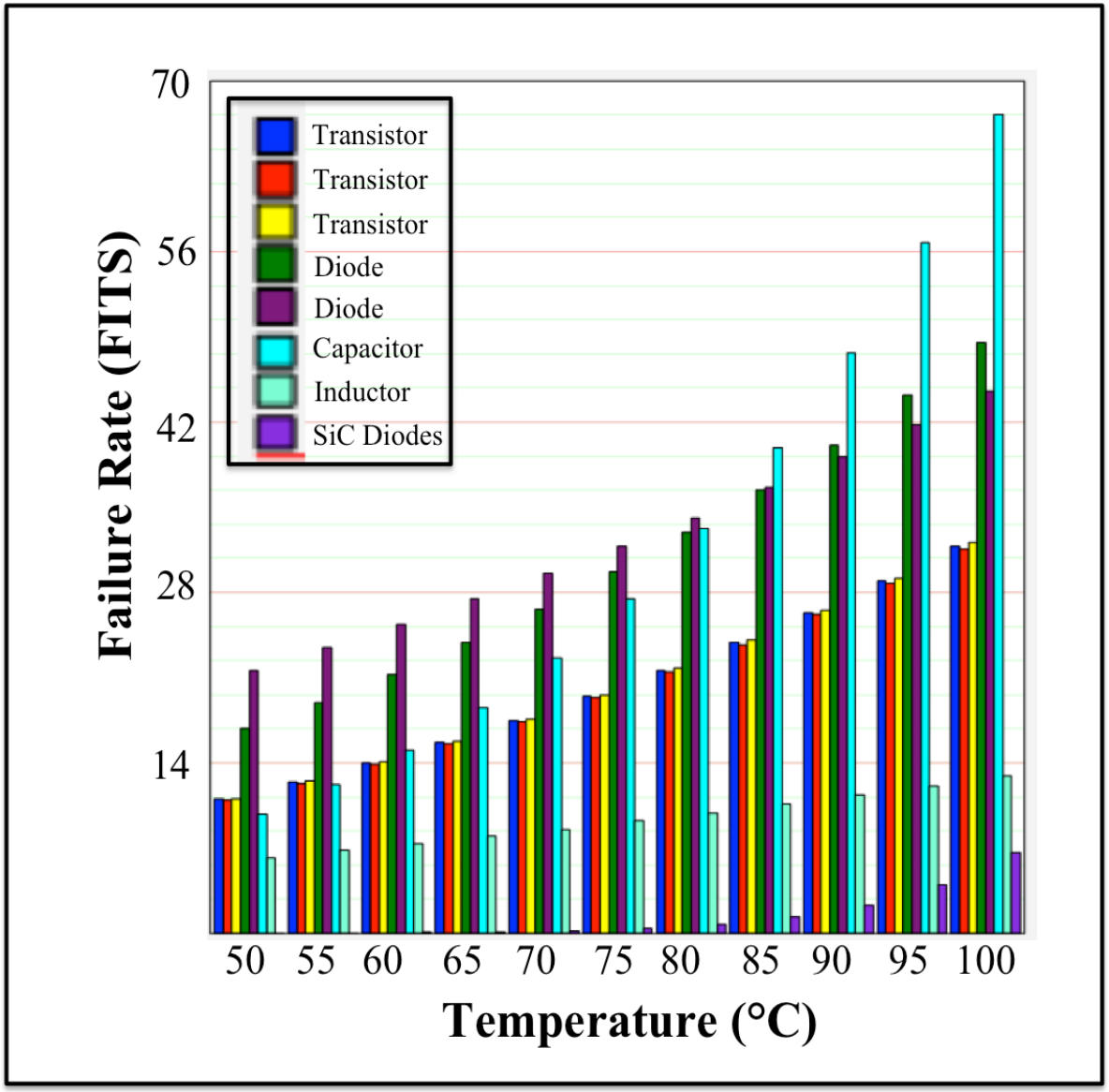
A collection of components

There is a certain level of art to today's reliability engineering. Design must be functional, prudent practices must be implemented

Capacitor value was modified:
L~(Va/Vr)^3

Could this explain the difference between string inverter FITs and MLPEs?

It's domain informed!



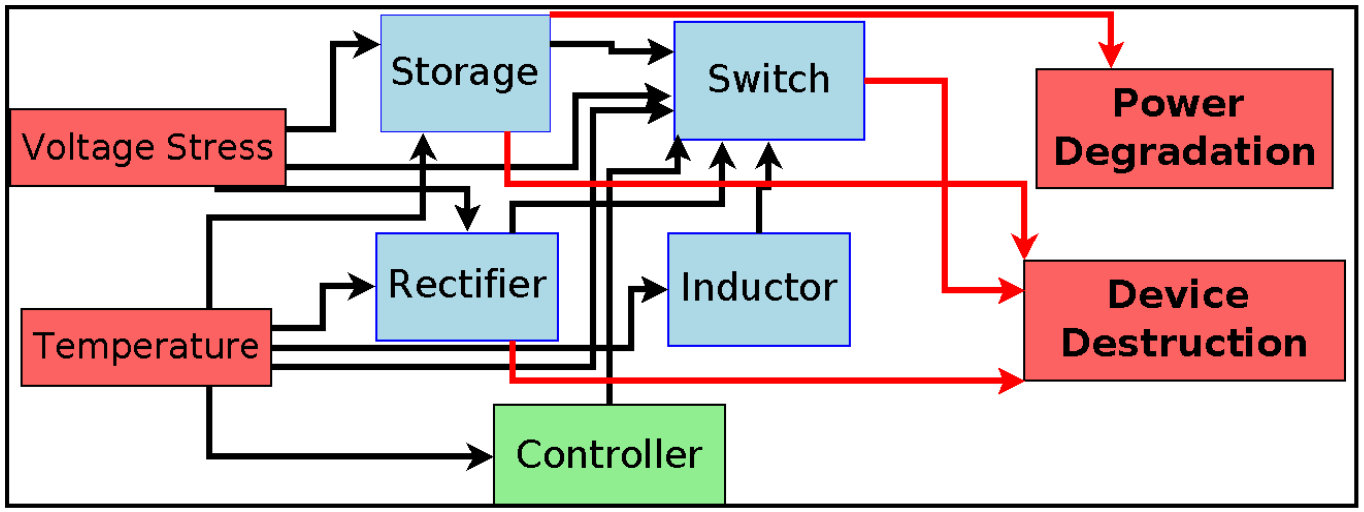
Critical to Lifetime Performance Components

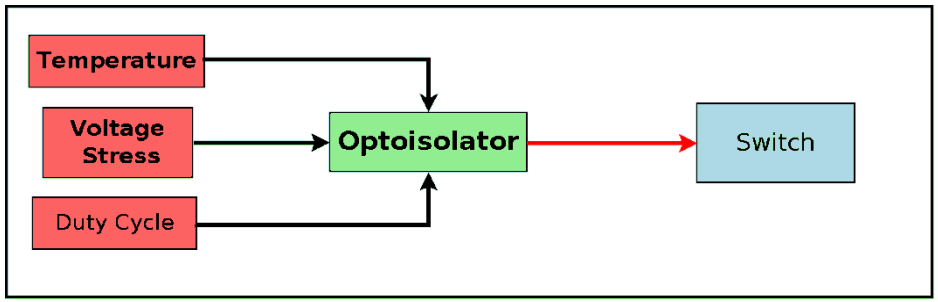
Component	MOSFET	e-Caps	Inductor	Sealants
Degradation	Die attach breakdown	Electrolyte dry-out	Lower Isat with temp	Embrittlement caused by hydrolysis
System response	Reduced efficiency	Increased ripple, reduced eff.	MOSFET degradation	Moisture ingress – MOSFET?

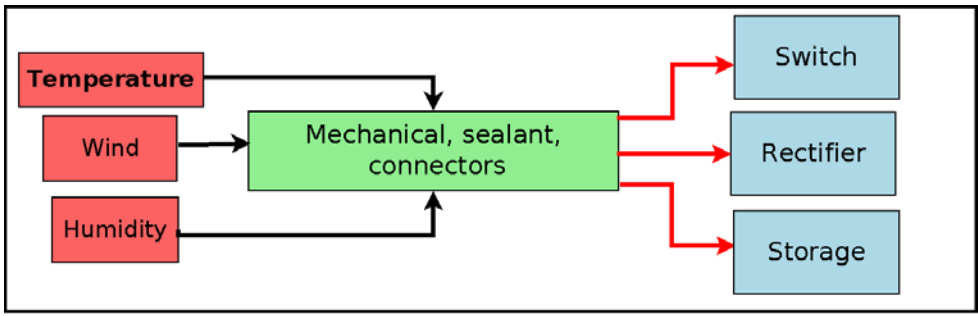
Here we can analyze the root cause of component degradation, so that it can be quantified.

Then interactions can be determined

Constructing a system technology model







Initial variables selected by domain knowledge.

Wrapping up

I don't believe one can make an arbitrarily reliable inverter because it's an ecosystem of components.

With Physics of failure and a mechanistic understanding of the degradation of the device one can use these data to “relax” to a good design.

We can develop “degradation pathway models” based upon structural equation modeling (SEM) that is informed by domain knowledge.

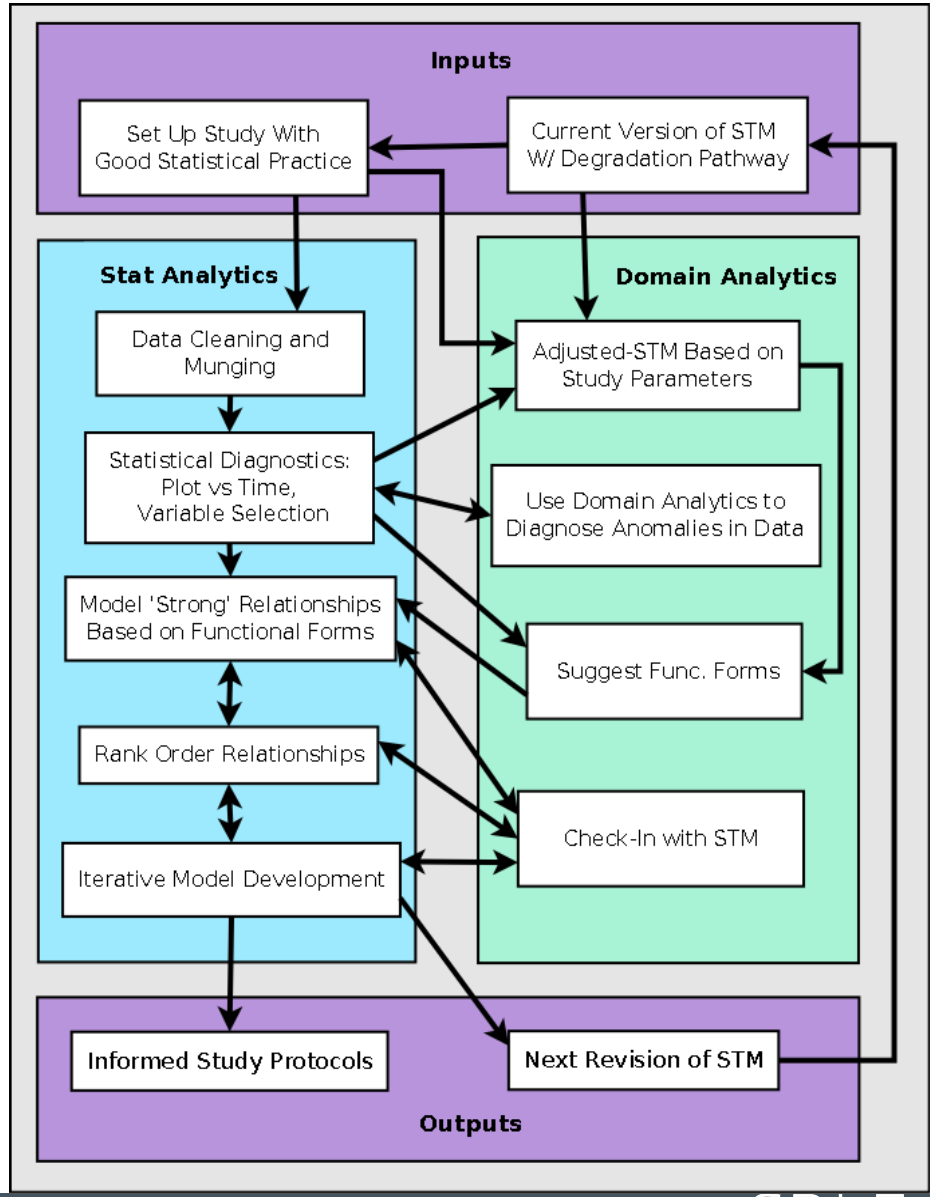
We can publicize this technique and these models and have them inform design, instead of settling on design and estimating the most unreliable components

How to achieve statistical significance

We employ a <u>domain knowledge</u> semi-supervised structure for determining study variables

Use Structural equation modeling to induce causal relationships between variables and predictors

SEM can be used both exploratory and confirmatory and is refined iteratively with inputs from statistical analytics and domain knowledge.



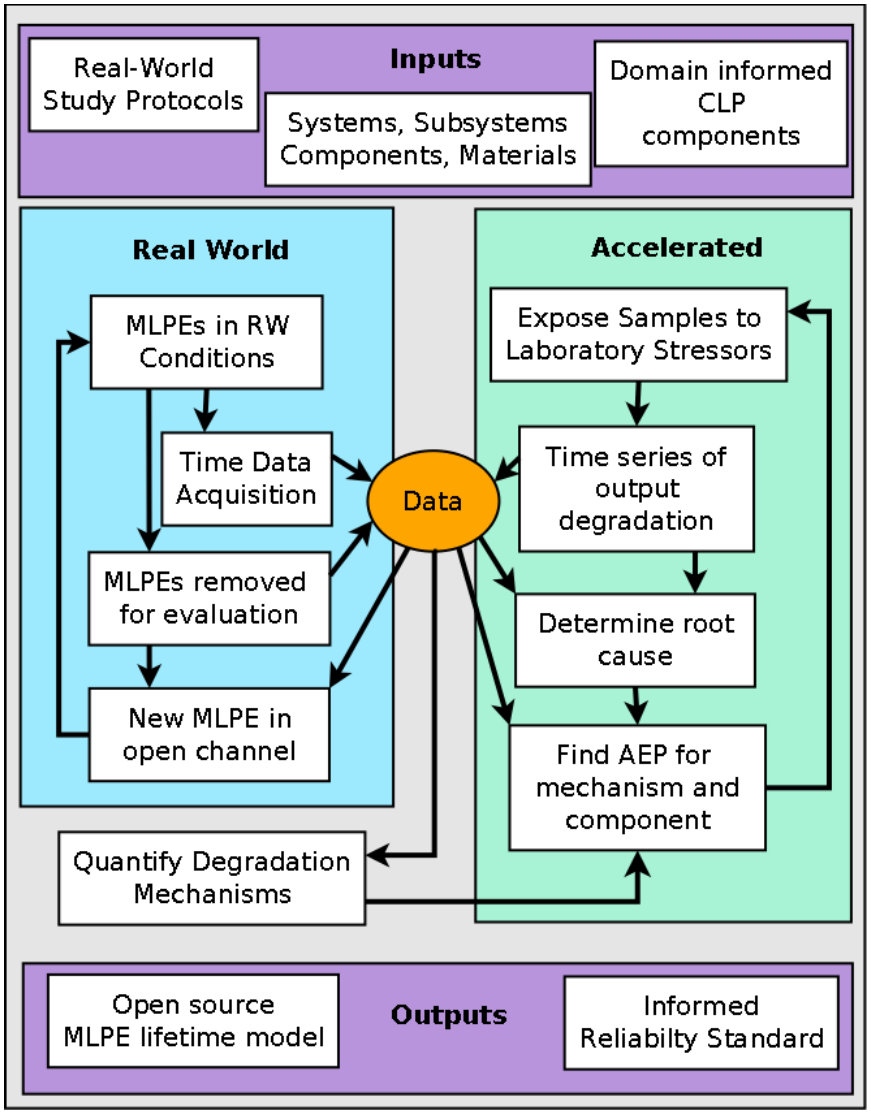
Developing accelerated test protocols

- Using time series analytics to determine real-world degradation

- Say what? OK, imagine your MLPE undergoes a “burst mode” at low powers, you amass these data, make a “cut” on low irradiance data.

- If you see a greater degradation rate in low power situations there's a mechanism:
- Burst mode deep cycles e-caps, which can overheat them, and cause wearout quicker.

- Also, at low power the converters are less efficient and can dissipate more heat
- We can decouple RW and accelerated studies.



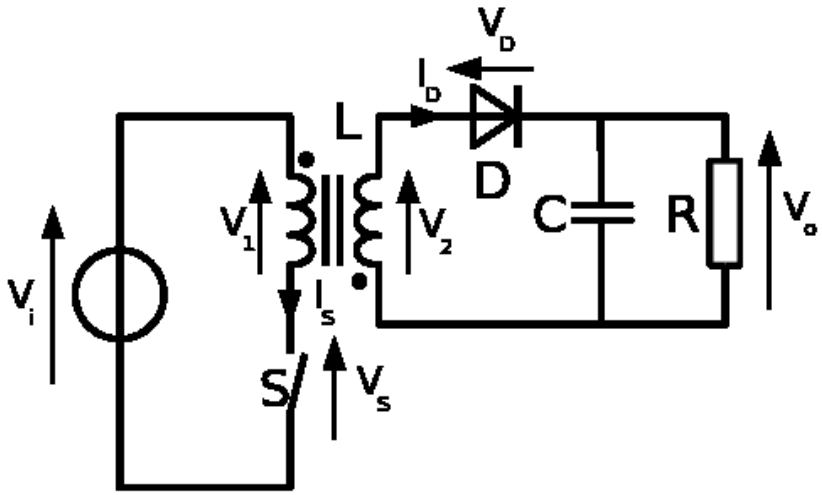
Boost Stage (12:1 boost ratio for microinverters)

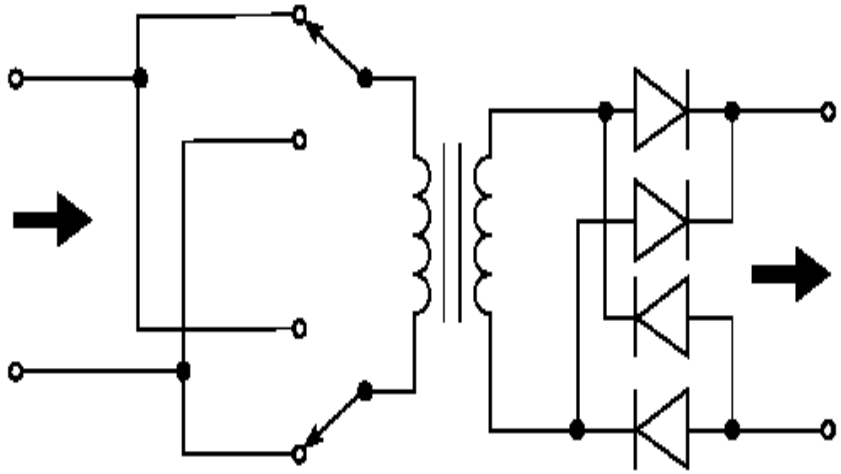
Single action: Flyback and Forward

- G = N*(D/1-D)
- Ramping up current into an "open" load
- Requires "snubbing" of some kind
- Active snubbing could enable ZVS
  - It's really low Q, and is often not too practical.

AC Coupling: Push/pull& Half Bridge

- G = N*D
- HB can naturally soft switch
- P/P can naturally clamp
- No storage in core
- Requires big transformer





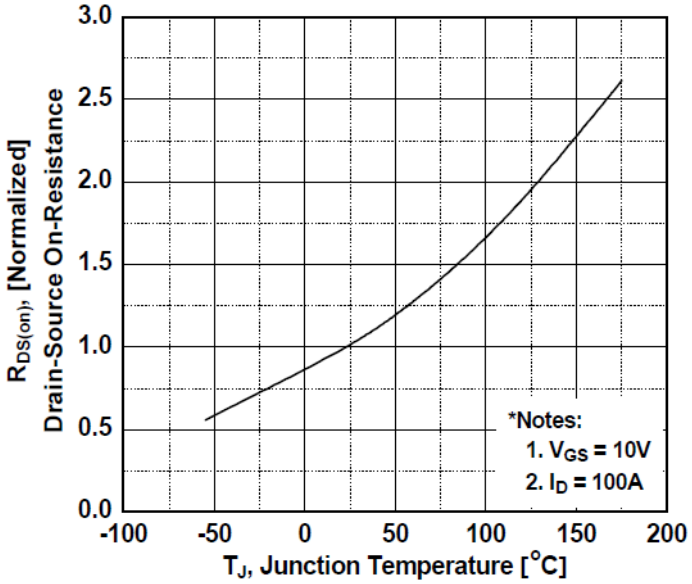
Why avoid the higher voltage MOSFET?

Let's take a look at the MIL HDBK 217

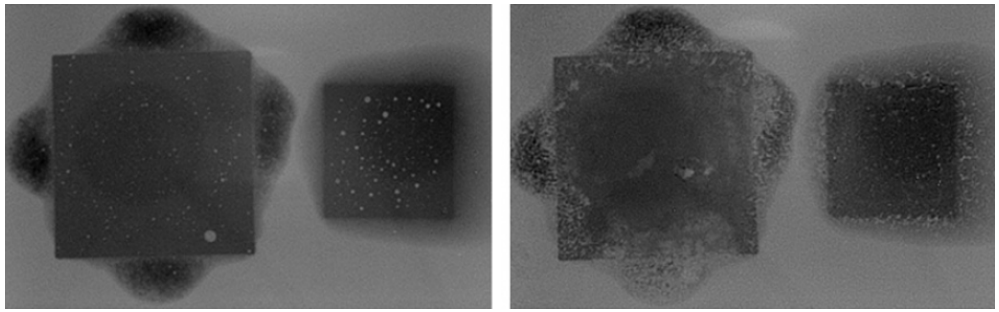
Lifetime varies ~linearly with voltage stress
But exponentially with temp.

Higher voltage, higher Rdson, and we never addressed the high current. So the FET may not avalanche but it's undergoing thermal runaway!

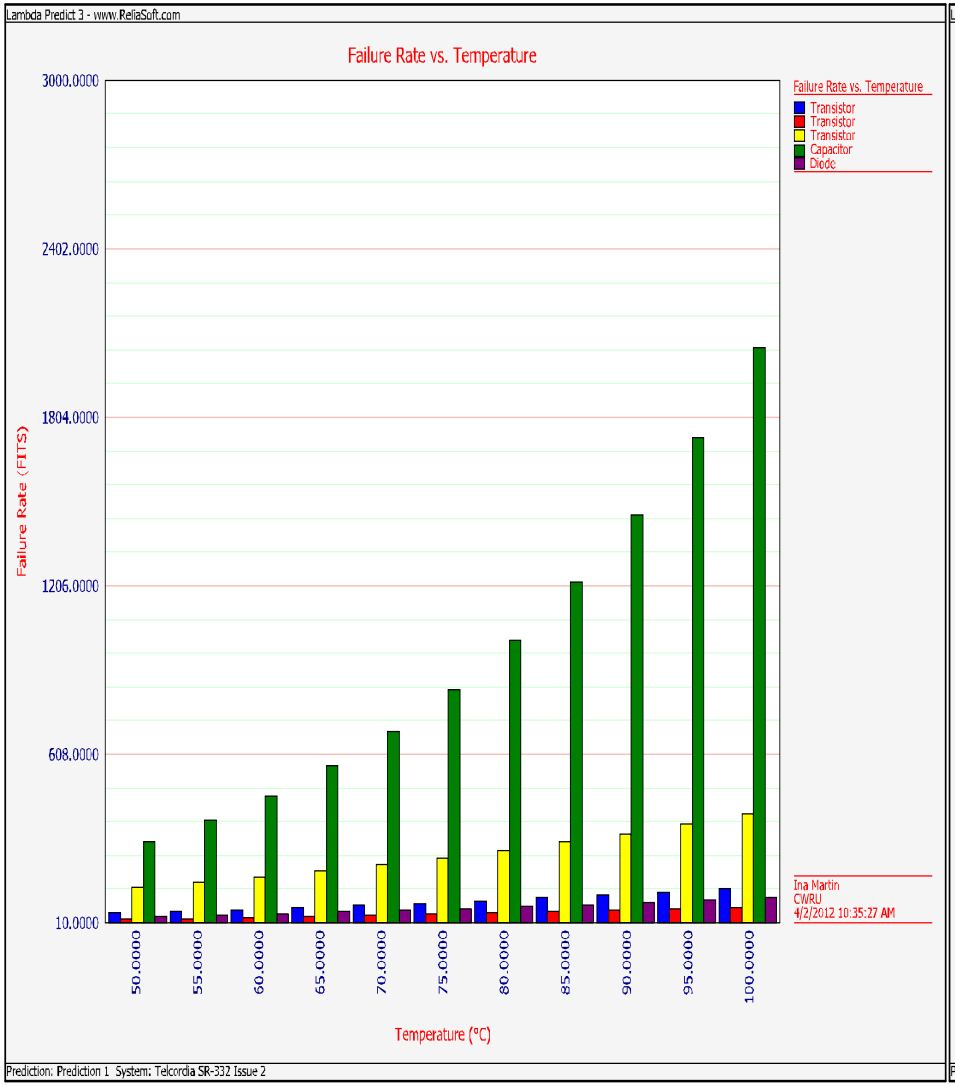
And we didn't even mention switching loss yet!

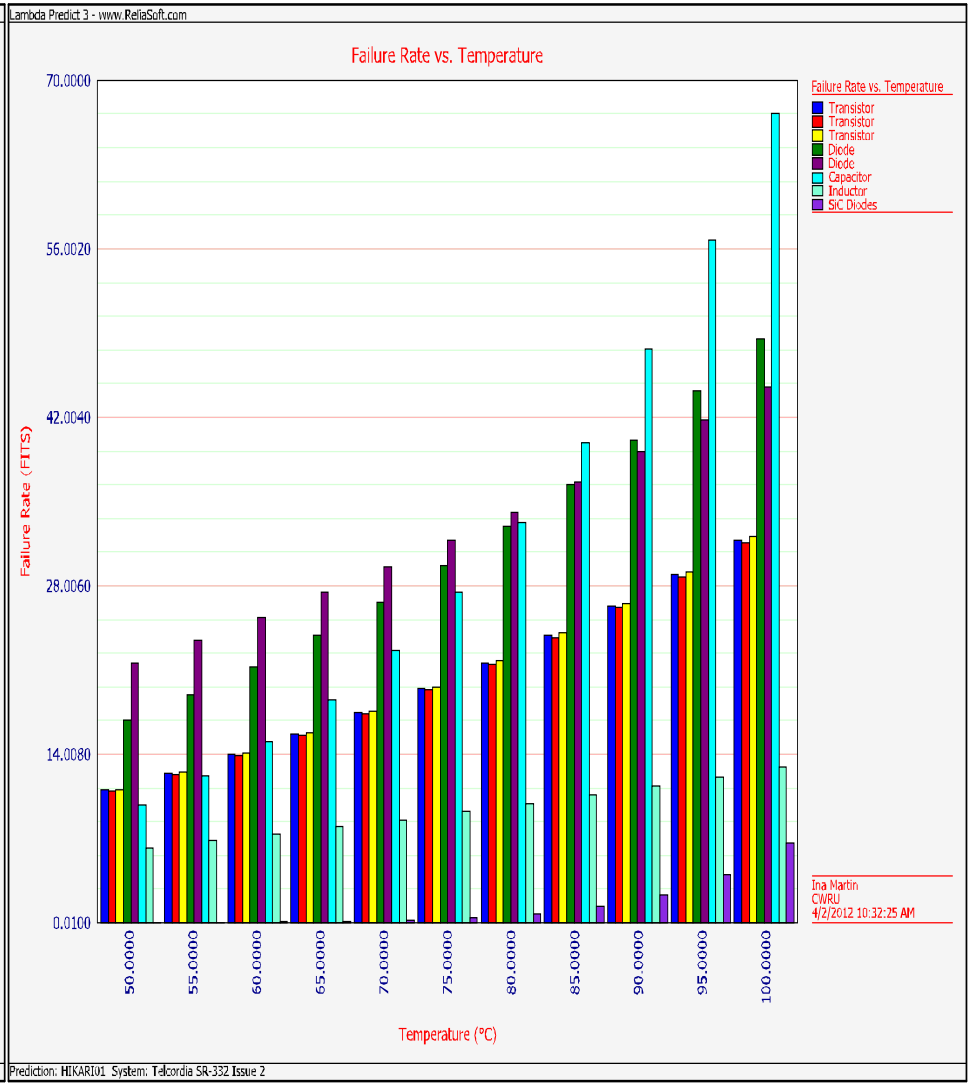


Physics keeps one from making an arbitrarily reliable inverter.



A collection of components





Questions

Can we sell a platinum inverter to a customer who will pay for quality/longevity and remove all doubt of reliability?
No.
Can we synergize low cost commodity electronics, reasonable performance and lifetime?
Yes. Thanks Charles.

String inverter = series connection
Microinverter = parallel connection

It's not that micros get to be more reliable they MUST be!