Effects of Reactive Power on Photovoltaic Inverter Reliability and Lifetime

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Introduction

- An inverter subsystem is critical for the overall PV system reliability
- An inverter system receives the largest amount of service calls for operation and maintenance [1]
- Physics of failure assessment using thermal cycling is used for determining overall system reliability and lifetime
- Mission profile of ambient temperature and solar irradiance translates into junction temperatures of power switches
- New grid codes [2] require PV inverters to provide reactive power support
- A mission profile approach was used to study the impacts of reactive power on the inverter system reliability and lifetime

Workflow used to calculate lifetime of inverters

1. Choose inverter topology
2. Datasheets, parameters, and values of switches, capacitors, and resistors
3. Develop loss model and thermal model in PLECS
4. Validate with hardware results
5. Develop electrothermal average model
6. Import mission profile for a year (Ambient temperature, solar irradiance)
7. Obtain yearlong values of junction temperature of switches
8. Use rain flow counting to identify number of cycles for each difference in junction temperature
9. Apply data from rain flow counting in the lifetime model of the inverter
10. Include the effect of reactive power by operating the inverter at same mission profile at non-unity power factors
11. Estimate lifetime of the inverter

Development of in-house inverter

- Two stage inverter rated at 1kW, with a synchronous DC-DC boost converter and H-bridge DC-AC inverter
- Inverter designed to operate in grid connected mode and has capability of reactive power support

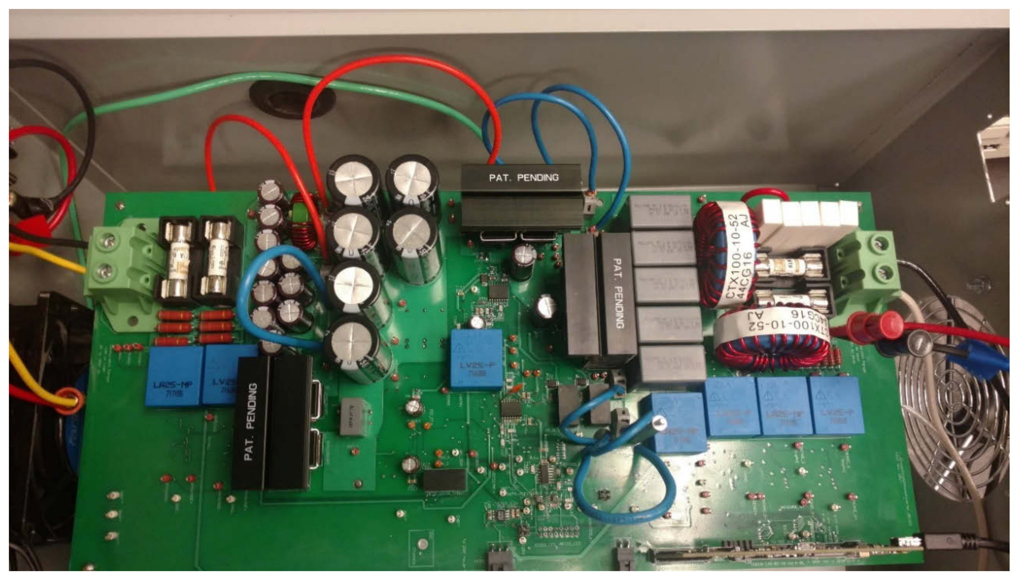
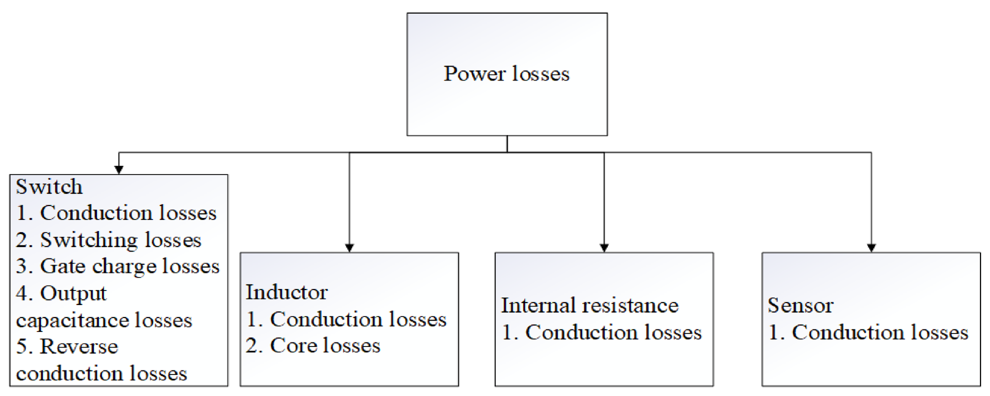


Photo by Ramanathan Thiagarajan, NREL

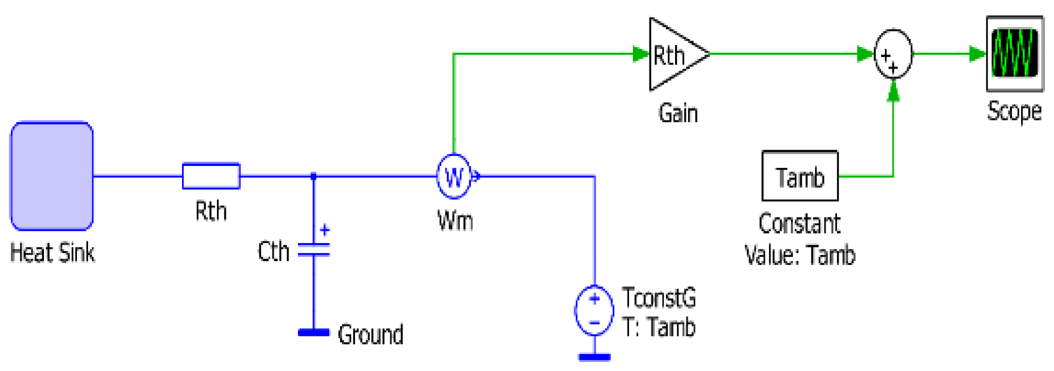
Loss model

- Loss model of the inverter was developed in PLECS
- Loss model included semiconductor losses, inductor losses, and conduction losses



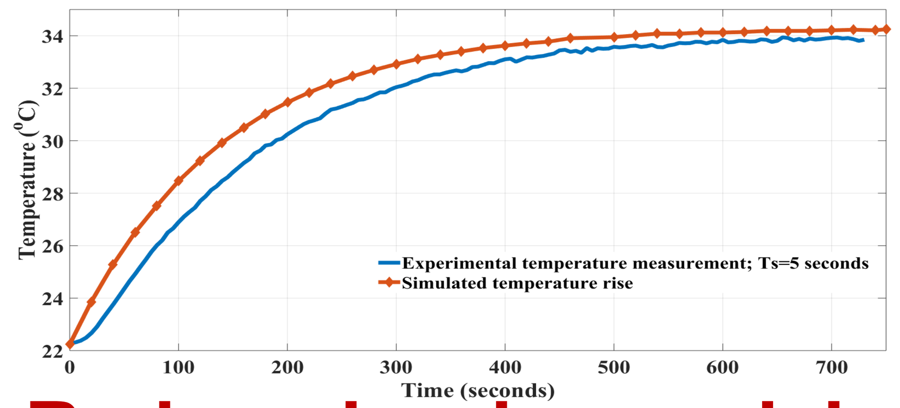
Thermal model

- Thermal model translates the losses calculated in loss model into increase in temperature of power device
- Thermal model described using lumped elements of thermal resistances and capacitances



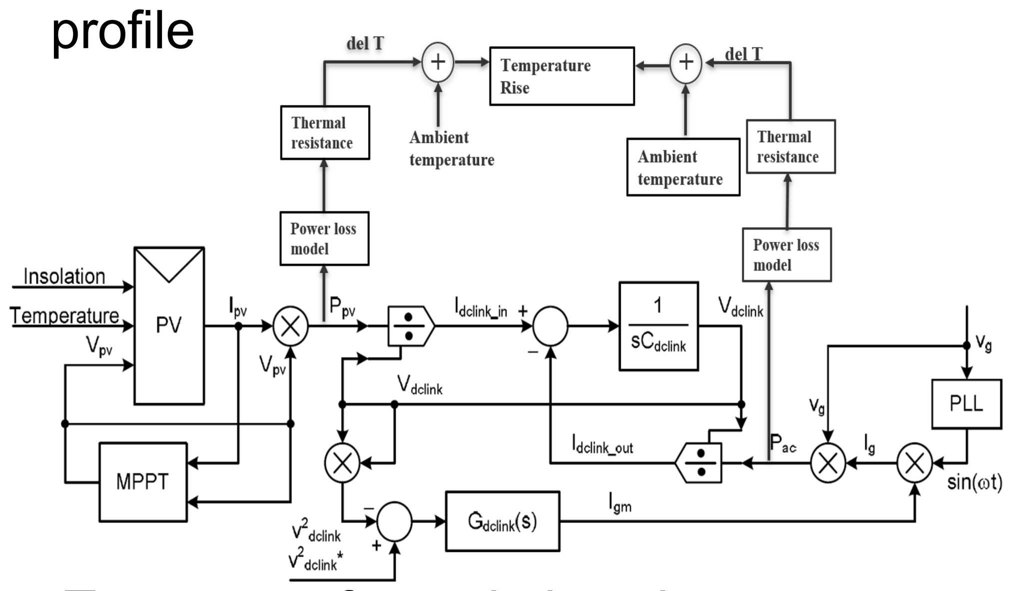
Results of electrothermal model

- Temperature measurements from the simulation verified with thermocouple measurements on the power switches of in-house inverter
- The temperature values from simulation matches the hardware measurements within 1°C accuracy at steady-state
- Model was validated by placing in-house inverter inside thermal chamber
- Inverter was operated at 500W in ambient temperatures of 25°C, 35°C , and 45°C and hardware results matched simulation values

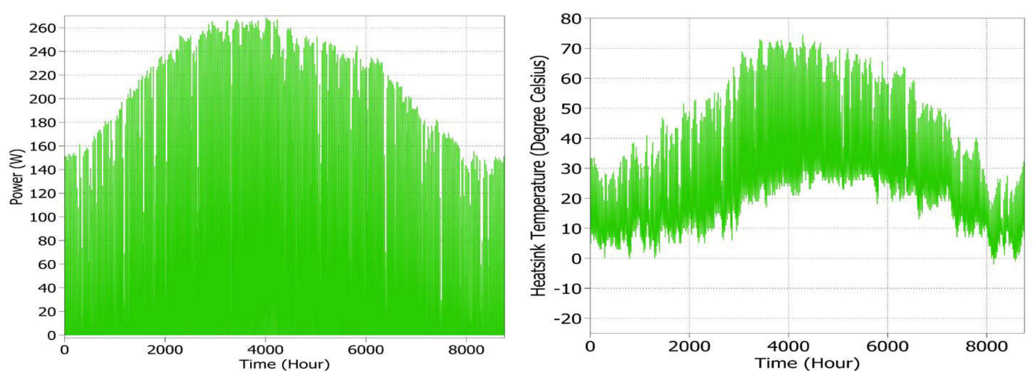


Reduced order model

- Computational time of a switching model is large for year-long profile
- Improved upon the reduced order model developed in [3] with thermal and loss model to measure temperatures over a year-long mission profile



- To account for variations in temperature and irradiance at a location over many years, the Typical Meteorological Year (TMY) data was used
- Two representative extreme hot and cold locations of Phoenix and Fort Peck were chosen



Lifetime model

- Rain flow counting used to record the number of device cycles, N_i, under each difference in junction temperature, ΔT_j
- A simplified Coffin-Manson model is used to estimate the number of cycles to failure, N_f

$$N_f = a \times (\Delta T_j)^{-n} \quad (1)$$

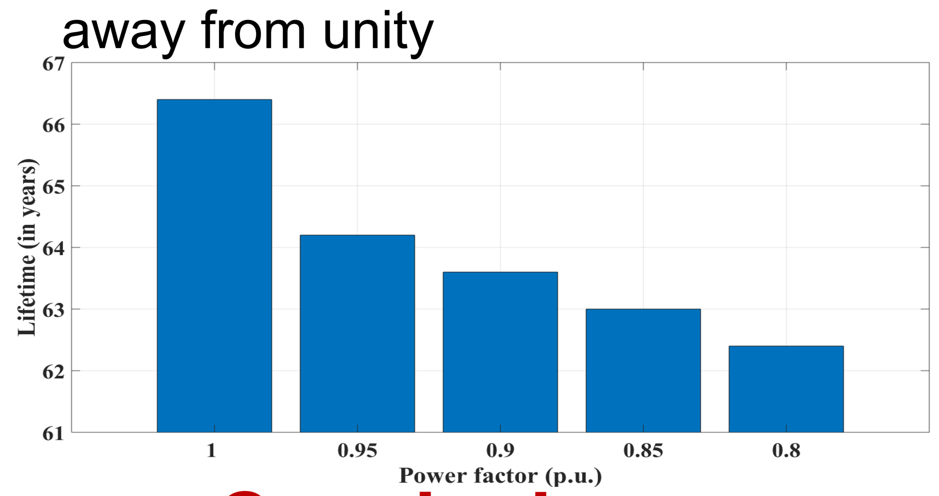
- N_f is related with the N_i to estimate cumulative damage, Q for various ΔT_j

$$Q = \sum_{i=1}^{n} \frac{N_i}{N_{fi}} \quad (2)$$

- The reciprocal, $\frac{1}{Q}$ gives the number of mission profiles the device can survive, defined as Remaining Useful Lifetime

Impact of reactive power

- Phoenix TMY reduced order model was repeated for non-unity power factors of 0.8 p.u. to 0.95 p.u.
- Results showed inverter lifetime decreasing as power factor moves away from unity



Conclusions

- Reduced order electrothermal model was developed from detailed switching model to translate mission profile data into junction temperature of switches
- Reduced order model was repeated for non-unity power factors
- Inverter lifetime reduces as the power factor moves away from unity

References

[1] Golnas, A., 2012, June. PV system reliability: An operator's perspective. *2012 IEEE PVSC.*

[2] IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces, in *IEEE Std 1547-2018*(Revision IEEE Std 1547-2003).

[3] Mao, X. and Ayyanar, R., 2009, February. Average and phasor models of single phase PV generators for analysis and simulation of large power distribution systems. *IEEE APEC 2009*.

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