DOE Office of Electricity TRAC

Peer Review

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

Intelligent Power Stages (IPSs)

PRINCIPAL INVESTIGATORS
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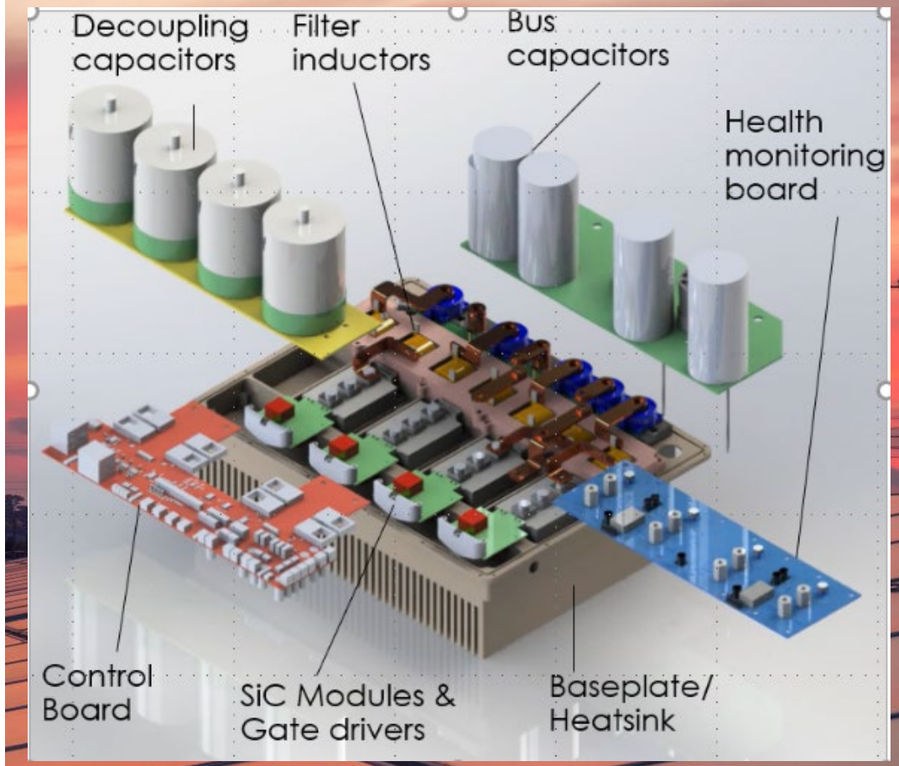
PROJECT SUMMARY

Smart Universal Power Electronic Regulators (SUPERs) & Intelligent Power Stages (IPSs)

The project focuses on developing and validating an intelligent power stage (IPS) incorporating system interoperability, diagnostics, and prognostics features.

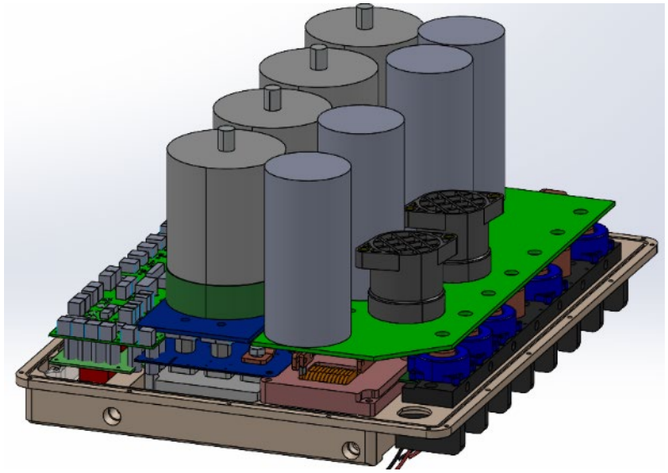
Innovations

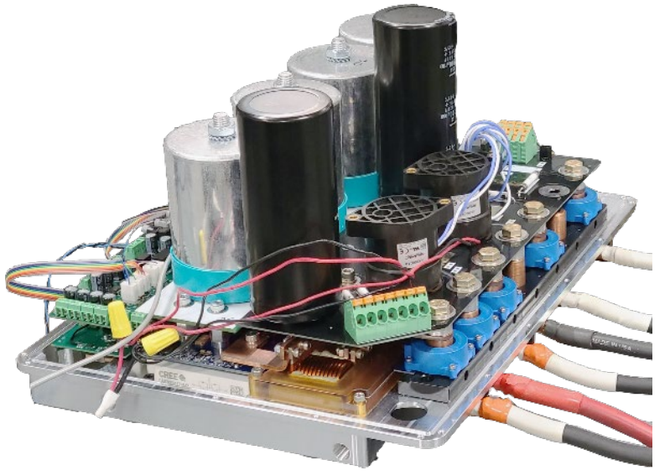
- Development of an interoperable inverter with a secondary controller (IPS-SUPER)
  - Operation of the IPS with an emulated SUPER with less than 1 switching cycle delay
- Development of key elements/sensors/modules to monitor and report on status of the IPS (Diagnostics and Prognostics)
  - Key feature for diagnostics: Shoot-through detection of SiC power modules
  - Key feature for prognostics: resistance change and characterization of SiC semiconductor power modules

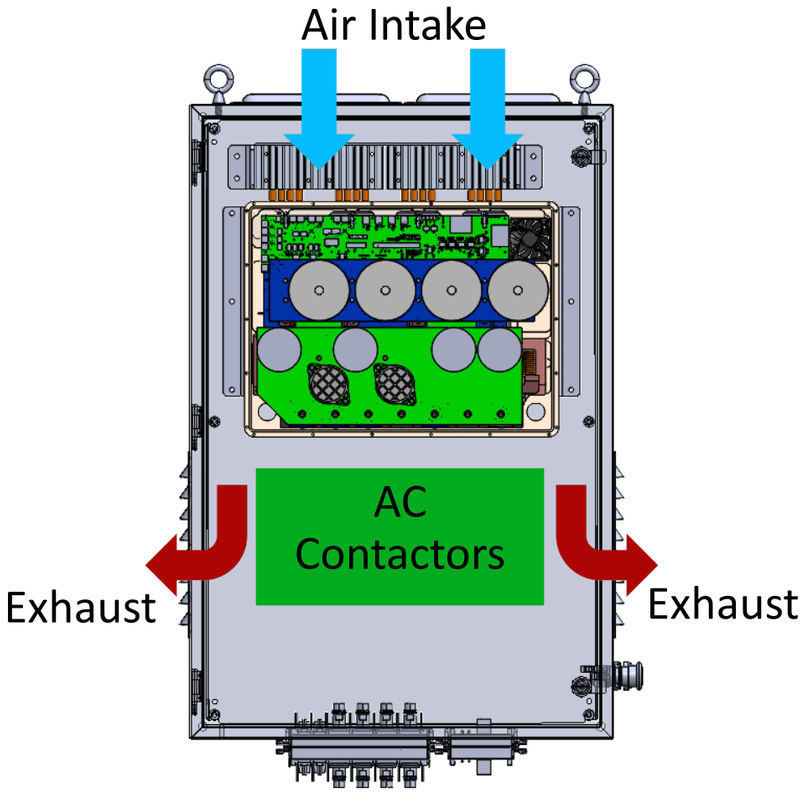


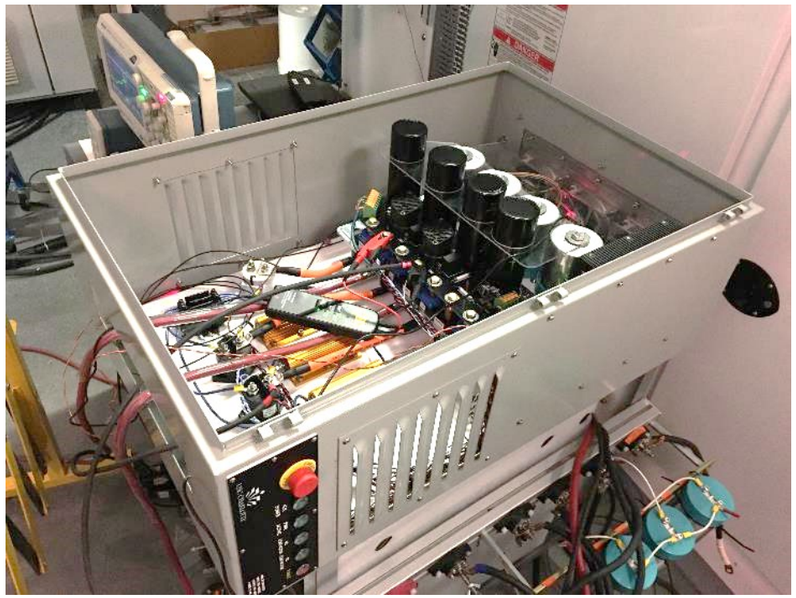
Innovation Update: IPS-SUPER Hardware

- *Interoperable Intelligent Power Stage (IPS)*



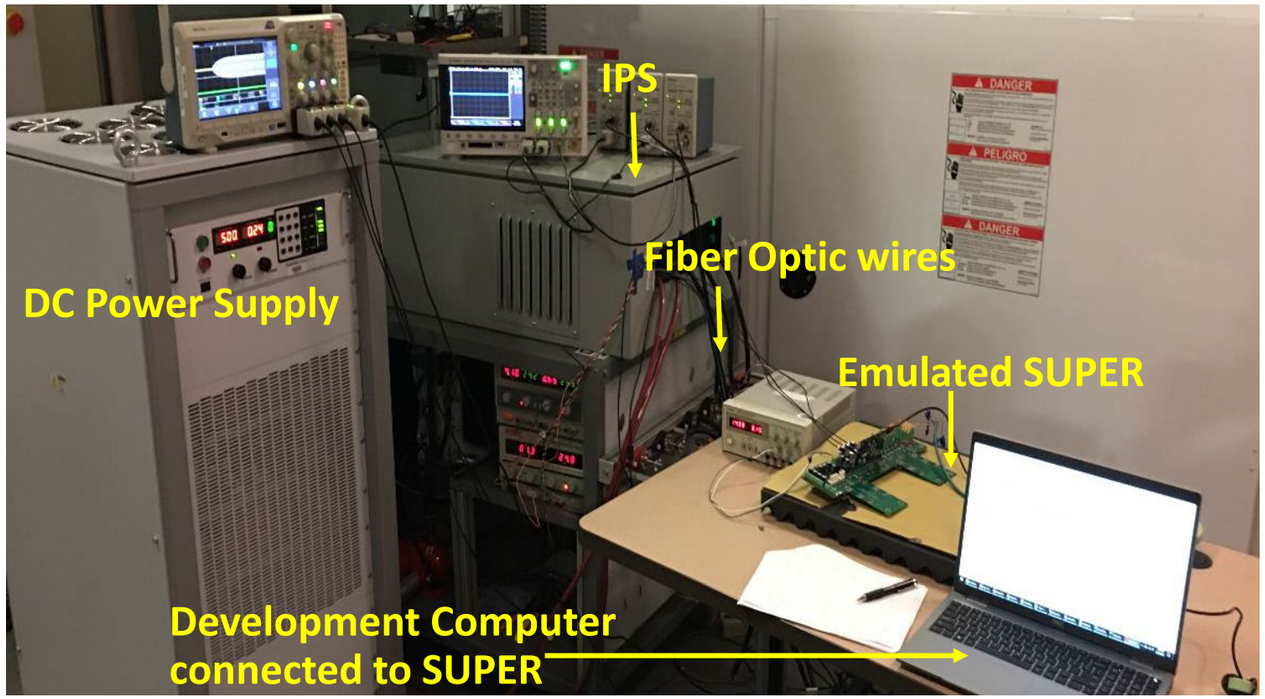


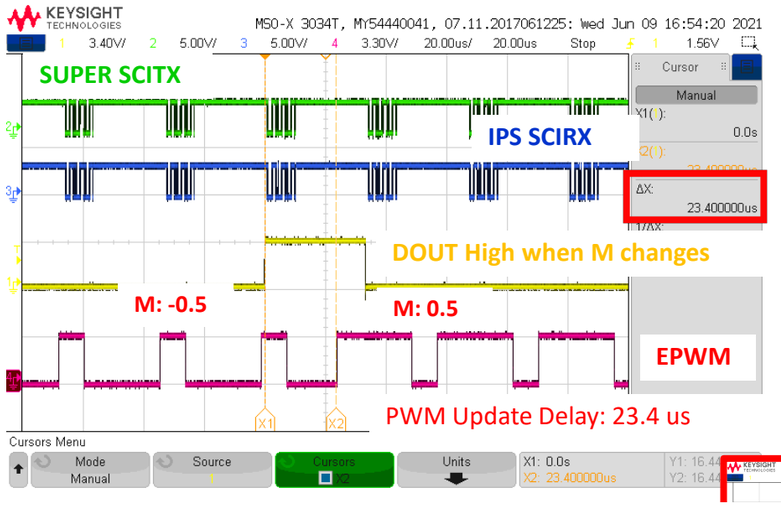


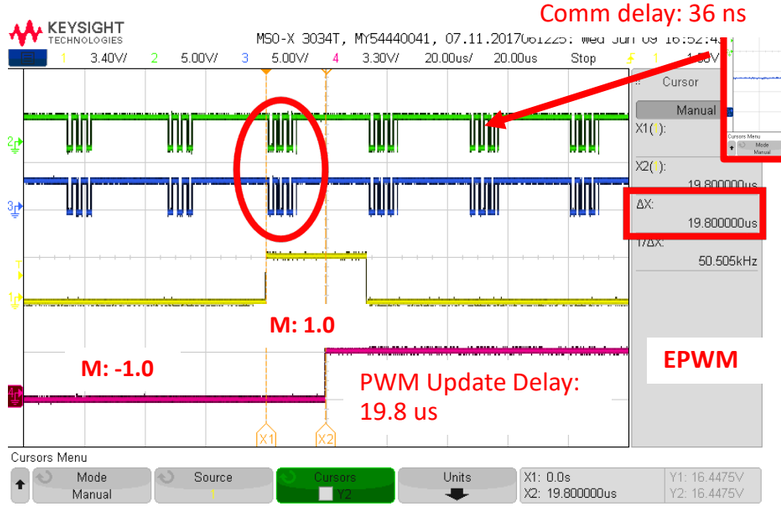


Innovation Update: Control Concept -1

- *Interoperable Intelligent Power Stage (IPS)*
  - Control Channel Communication Characterization
    - Verified the delay is within one switching cycle

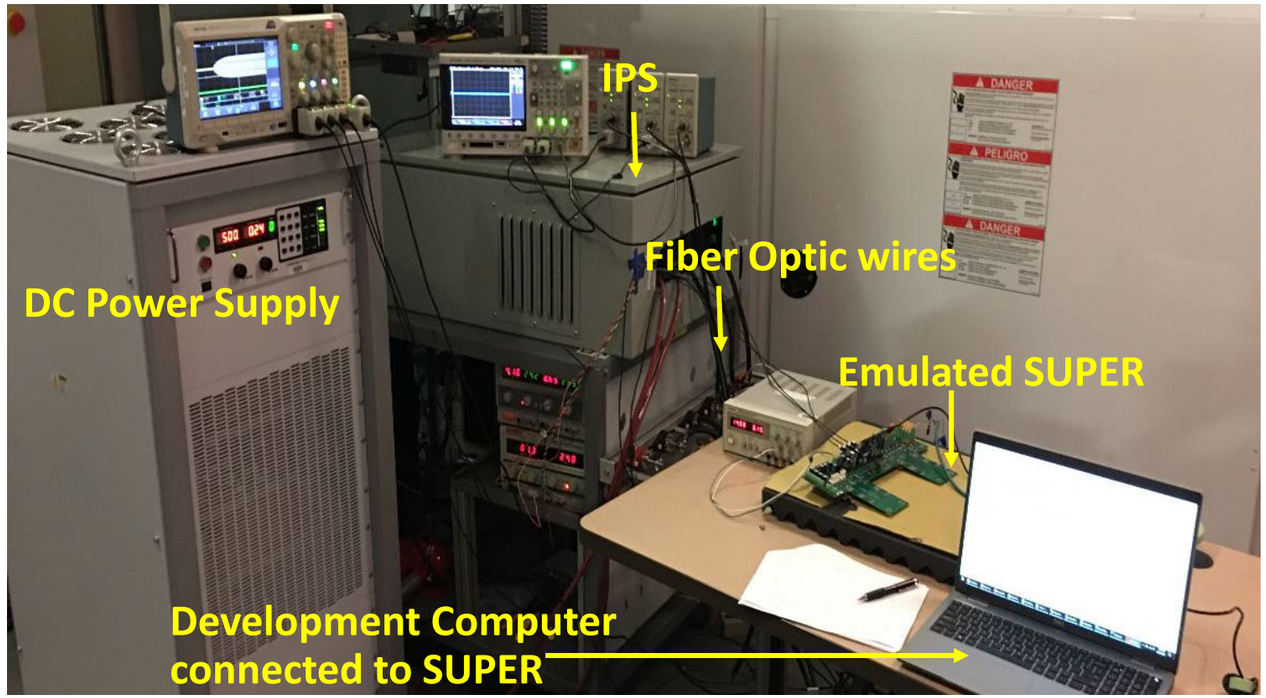


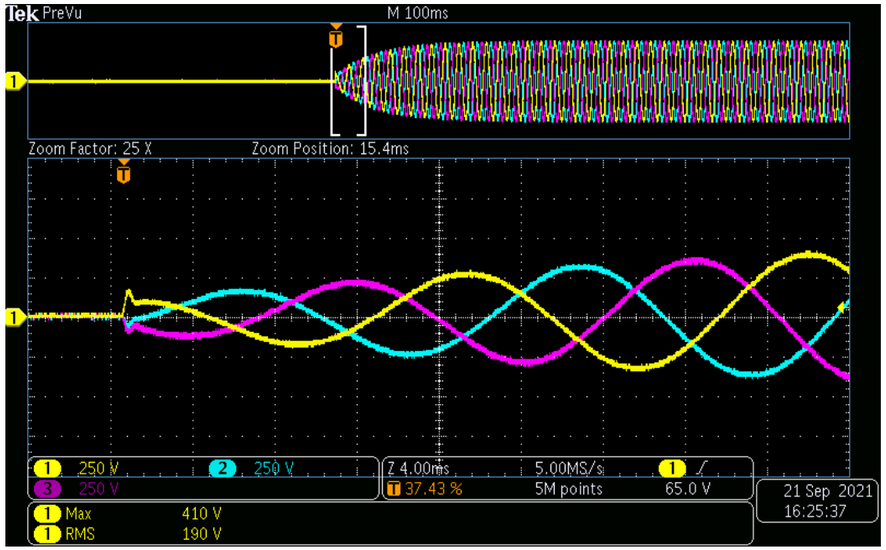




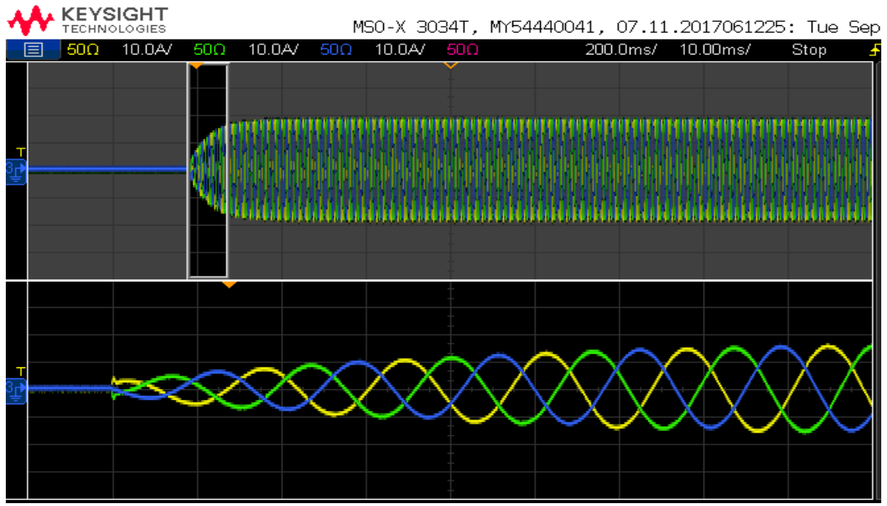
Innovation Update: Control Concept-2

- *Interoperable Intelligent Power Stage (IPS)*
  - Closed-loop (voltage-mode) at 10kW, 480VAC, 800VDC





3ϕ L-L voltages



3ϕ phase currents

Innovation Update: Robustness

- *Interoperable Intelligent Power Stage (IPS)*
  - Open-loop Control through Emulated SUPER at 75kW, 480VAC, 900VDC

- 98.36% efficiency was obtained

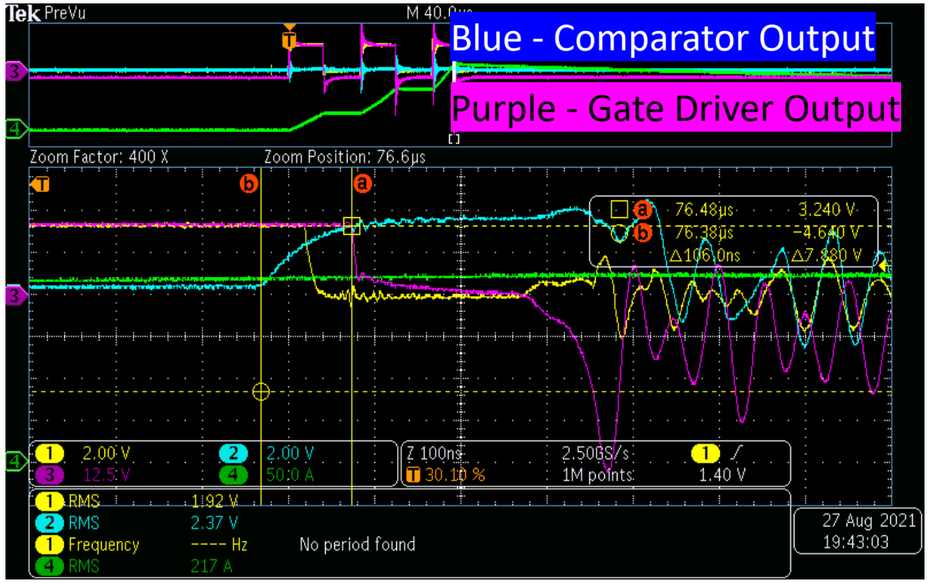
P_{IN}	P_{OUT}	η	P_{LOSS}
77.13 kW	75.87 kW	98.36 %	1.26 kW

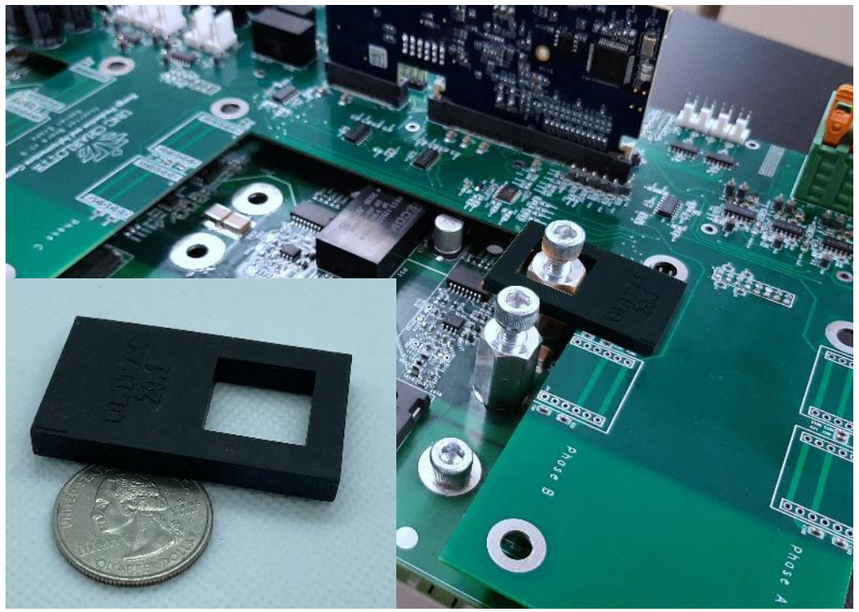
- Waited until the equilibrium temperature point (saturation point)

Module-PhA	Module-PhB	Module-PhC	Module-PhN	Ambient
49.7 °C	52.9 °C	46.8 °C	32.0 °C	25 °C

Innovation Update: Shoot-Through Sensor

- *Diagnostics: Shoot-Through Protection*
  - Typical de-saturation technique delay is greater than 2 microseconds and highly depends on temperature.
  - Shoot-through alarm & protection in less than 400 nsec.
  - Inverter tripped at 220 Apeak.

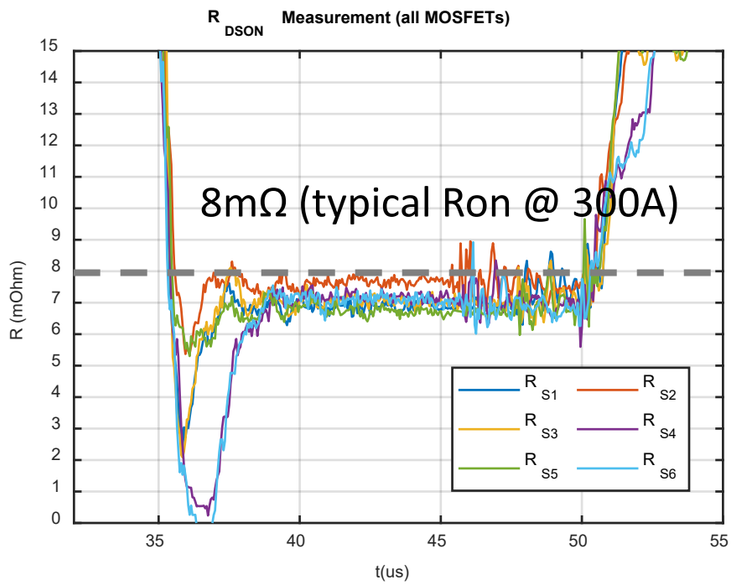




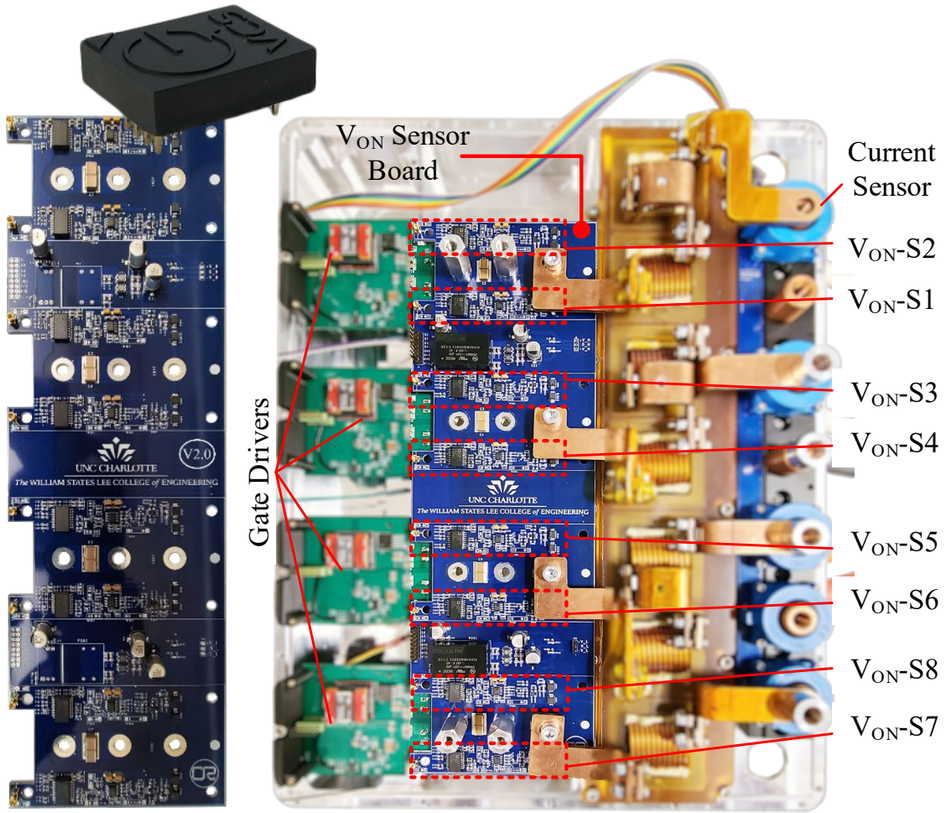
Symbol	Description	Time
T_{comp}	Comparator Propagation Delay	76 ns
T_{GPIO}	GPIO Input – RC Pullup Time	32 ns
T_{MCU}	ePWM Trip Latency	20 ns
T_{GD}	Gate Driver Delay	53 ns
T_{SiC}	SiC Module Turn Off time (datasheet)	219 ns
T_{total}	**Shoot-through protection delay**	**400 ns**

Innovation Update: R_{ON} Sensor

- *Prognostics: In-situ real-time R_{ON} Estimation*
  - Developed isolated sensors and an algorithm to monitor the on-state resistance of SiC power modules,
  - Average reporting, one value/second to SUPER: two-four samples per switching cycles, > 30 A.
  - Relative parameter (value) to each device baseline value will be reported to SUPER or IPS-edge processor



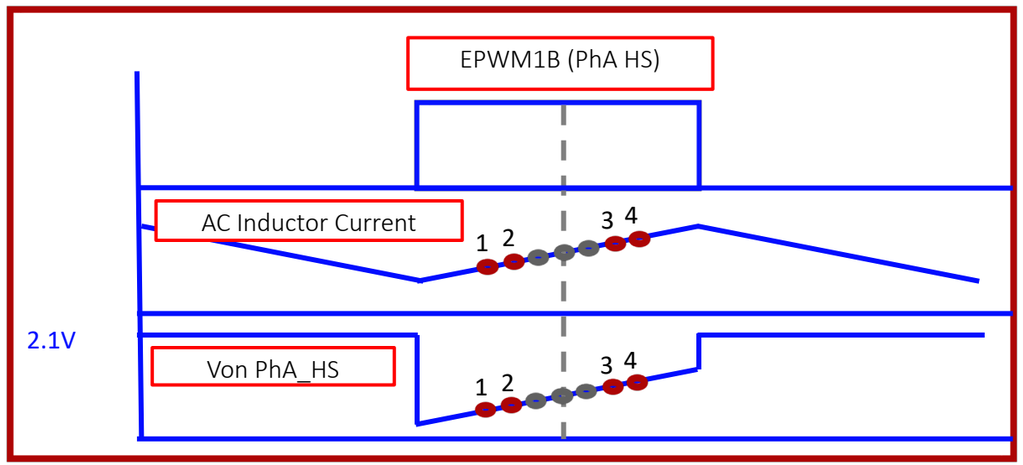
Device	RON Measured (mΩ)
S1	6.88
S2	7.69
S3	7.09
S4	7.27
S5	6.81
S6	7.14

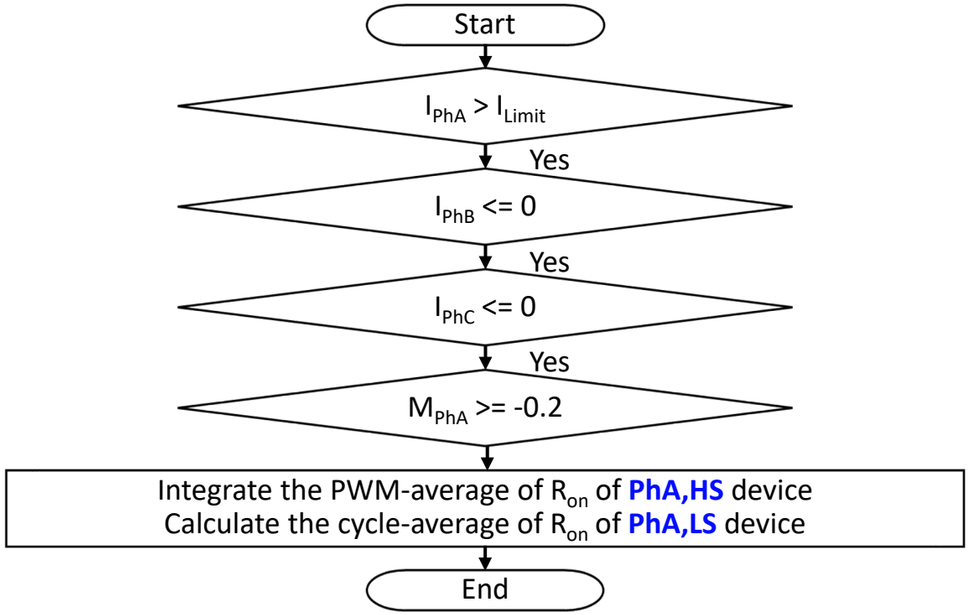


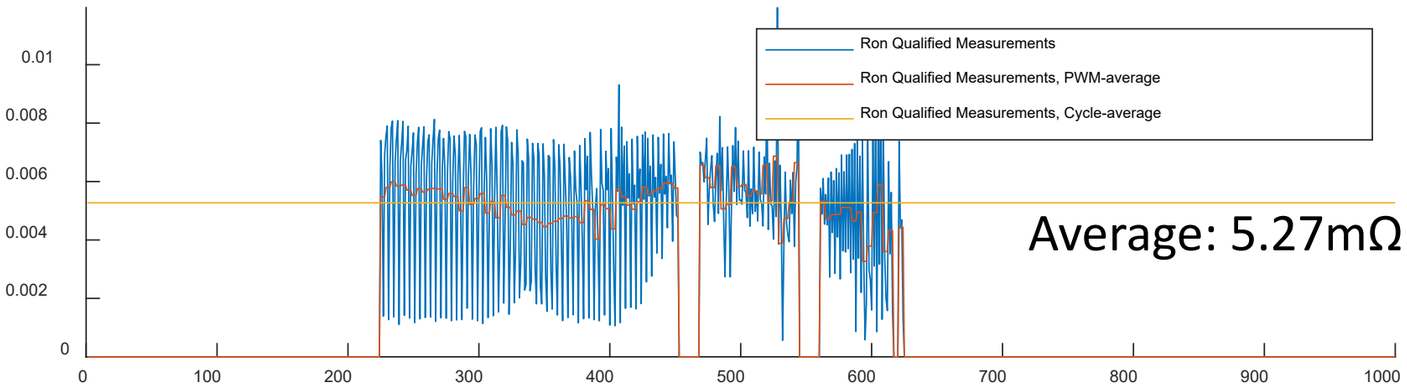
Conditions: 1kVDC, 140Amax, DPT (Second pulse)

Innovation Update: R_{ON} Algorithm

- *Prognostics: In-situ real-time R_{ON} Estimation - 2*
  - Multi-sample averaging approach

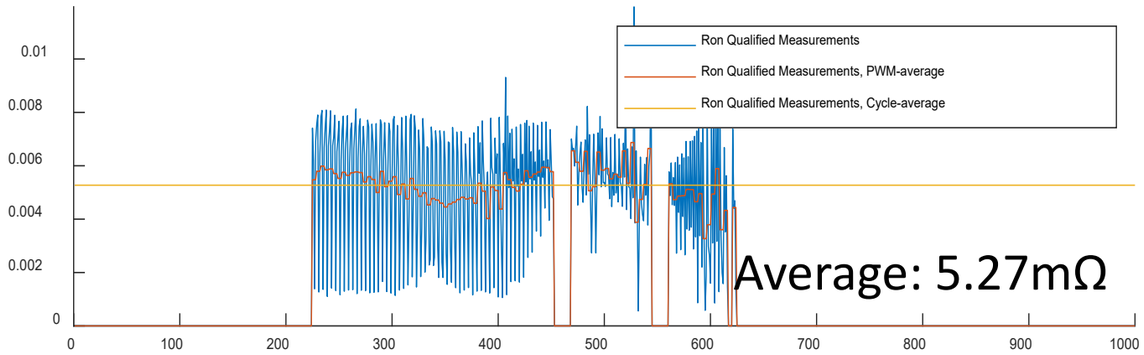




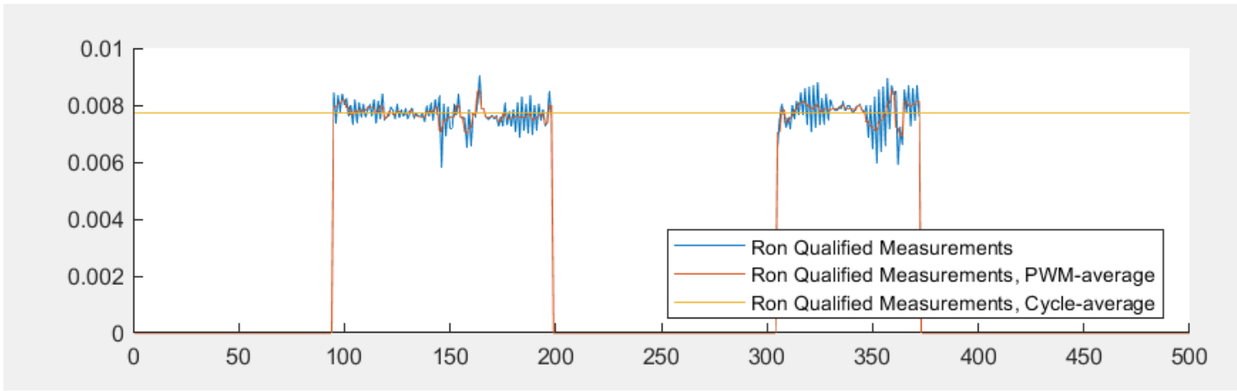


Innovation Update: R_{ON} Consistency

- *Prognostics: In-situ real-time R_{ON} Estimation - 3*
  - To improve the consistency: hardened the sensing hardware and developed a data qualification algorithm



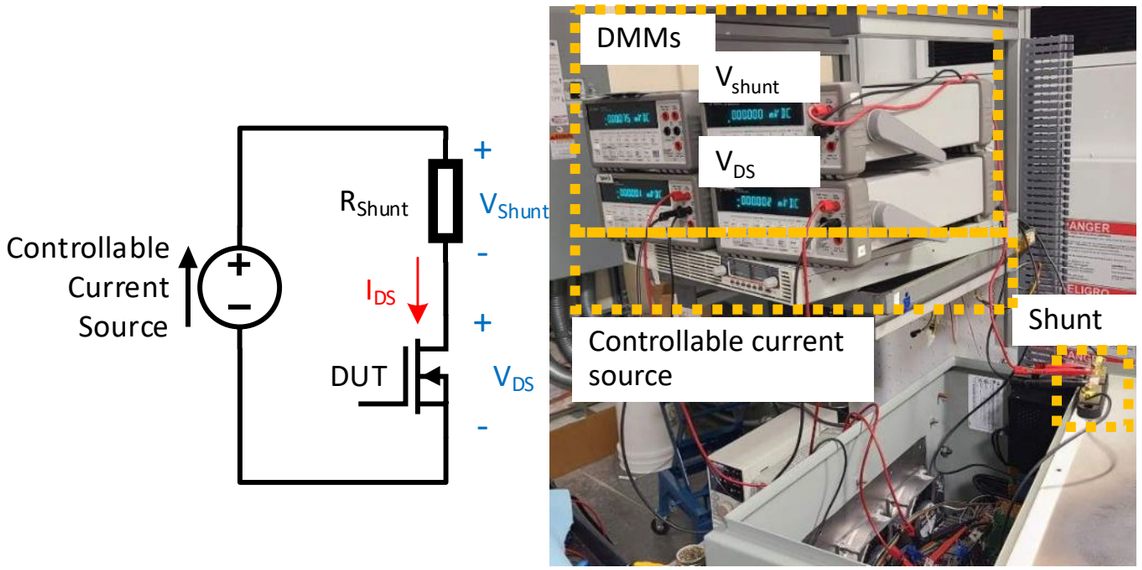
After Data Qualification

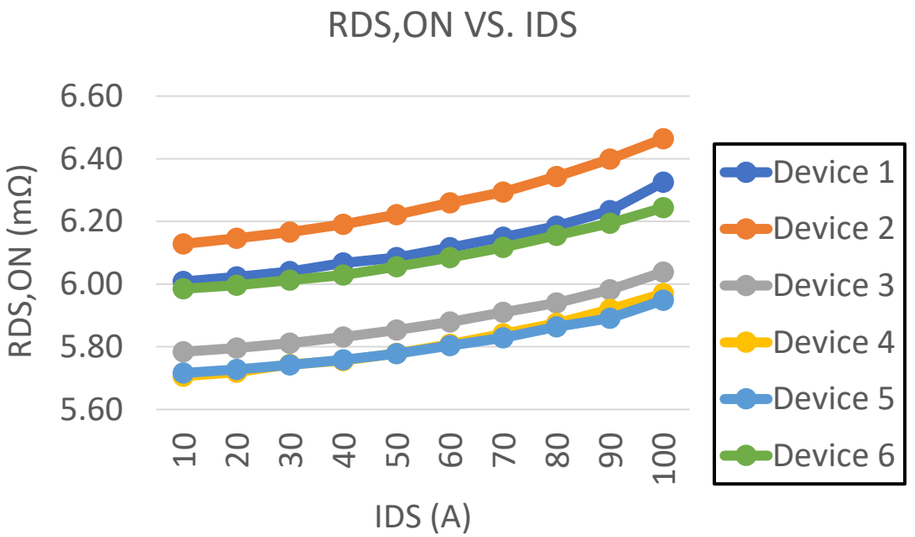


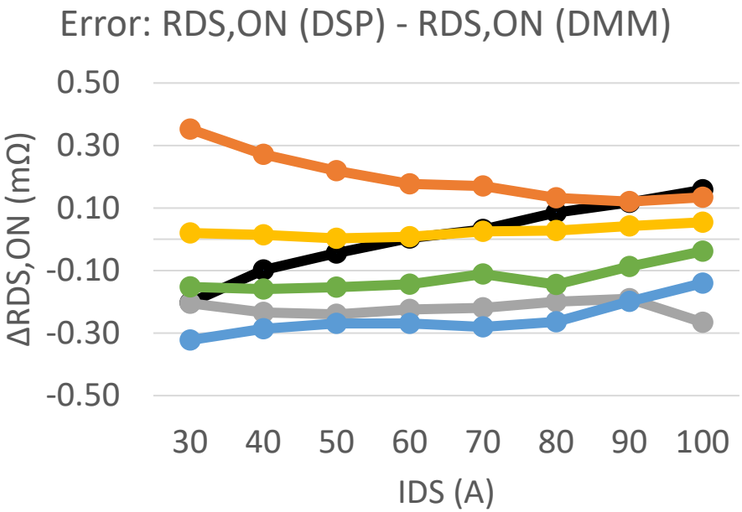
Cycle-Avrg	PhA,HS	PhA,LS	PhB,HS	PhB,LS	PhC,HS	PhC,LS
MATLAB	7.72	7.67	6.01	6.83	7.03	6.59
IPS DSP	7.71	7.67	6.02	6.82	7.02	6.58

Innovation Update: R_{ON} Accuracy

- *Prognostics: In-situ real-time R_{ON} Estimation - 4*
  - A true (offline) on-resistance set up developed to measure the reference values for six devices
  - Observed differences from -0.32mΩ to +0.35mΩ which is equivalent to 5%-7%







Innovation Update : Future

- Calibration of the relative R_{ON} based on the current value and temperature
- Health monitoring of electrolytic DC link capacitors in IPS.
- Development of algorithm identifying the health status of the DC link capacitors.

Impact/Commercialization

- Include the impact/commercialization status here:

With our industrial partners, an LOI is submitted to DOE SBIR program under DE-FOA-0002555 to commercialize and demonstrate the developed sensors and features in a commercial inverter

IP STATUS

Provisional patent application:
Title: On-State Voltage Measurement of High-Side Power Transistors in Three-Phase Four-Leg Inverter for In-Situ Prognostics
No.: 63/203,405
Inventor(s): Chondon Roy, Namwon Kim, James Gafford, and Babak Parkhideh
Status: Filed new provisional patent application.

THANK YOU

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