Universal Off-Grid Microconverter – *Solar Plug*

Georgia Tech Center for Distributed Energy

System Overview:

✓ Objective

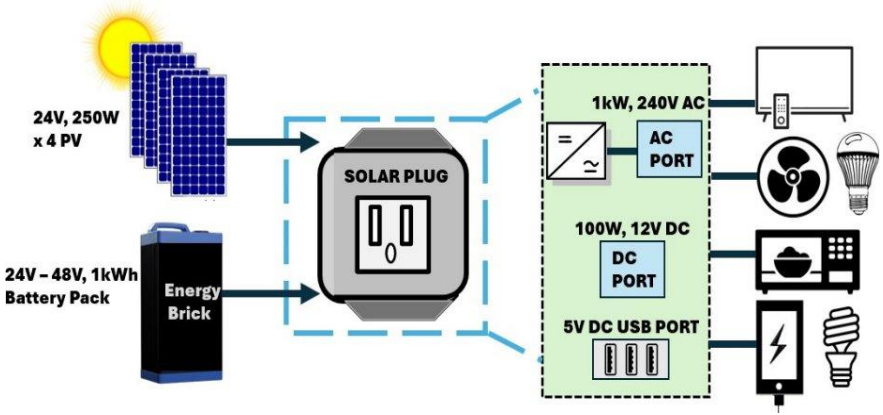
- Provide **affordable**, **scalable**, and **reliable** power to off-grid communities, addressing the energy needs of households and small businesses.

✓ System

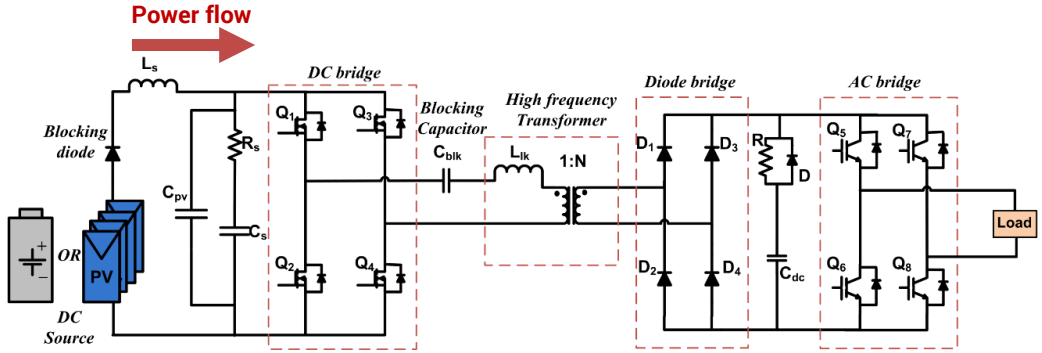
- Flexibility for AC & DC loads for Tier 1-4 Access
- AC Port: 240V, 1kW
- DC Port: 12V, 100W
- USBA/C Ports for low-power appliances
  - Overnight backup enabled by 3.7V Li-ion cell batteries.

✓ Power Sources

- Multiport operability directly from PV panels or battery pack



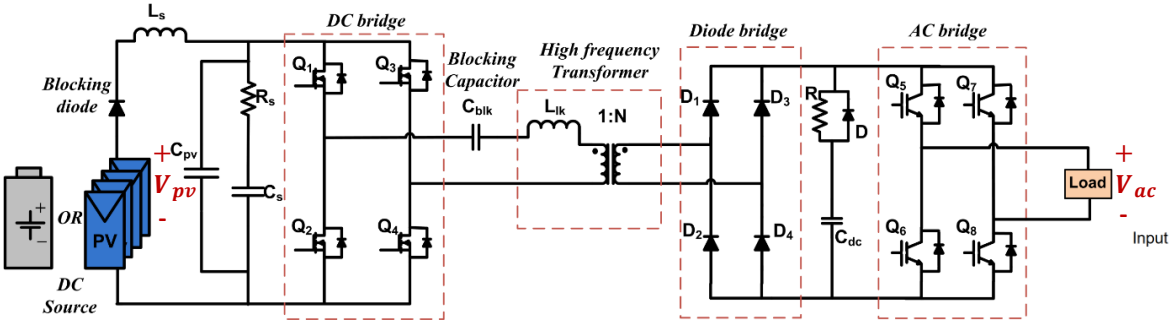
System block diagram of the Solar Plug

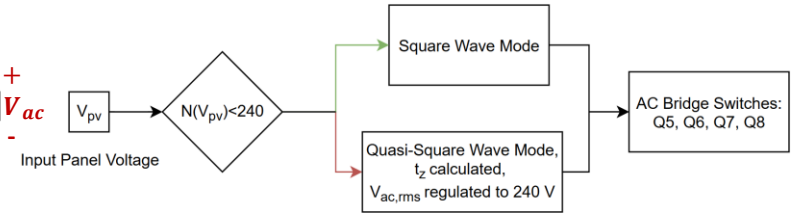


Circuit diagram of the proposed converter

N. Prabhu, **S. Manjrekar**, R. Sriram, A. Marellapudi, J. Benzaquen and D. Divan, "Solar Plug – Universal Off-Grid Microconverter for Low-Cost Tier-1-4 Energy Access," *January 2025 International Decentralized Energy Access Symposium (IDEAS)*, doi: 10.1109/IDEAS62193.2025.11157522.

Operating Principle – *Overview*





✓ DC-DC Stage

- DC Bridge switches at f_{sw} with 50% duty cycle
- Transformer (1:N) steps voltage up: NV_{pv}
- Diode Bridge rectifies voltage across C_{dc}

✓ DC-AC Stage

- **Square Wave Mode**: AC Bridge switches at f_o with 50% duty cycle (when $V_{pv} < \frac{240}{N}$)
- **Quasi-Square Wave Mode**: AC Bridge introduces **Dwell Time** to regulate RMS voltage to 240V (when $V_{pv} > \frac{240}{N}$)

Dwell Time, t_z when $V_{pv} > \frac{240}{N}$

$$t_z = \frac{t_o}{2} \times \left(1 - \frac{240^2}{(NV_{pv})^2}\right)$$

t_o : AC Voltage time period; $\left(\frac{1}{f_o}\right)$ where $f_o = 50/60Hz$

N: Transformer Turns Ratio

V_{pv}: Panel Voltage

V_{pv}	Mode	Dwell time t_z	Positive State		Negative State		Zero State	
			ON	OFF	ON	OFF	ON	OFF
$< \frac{240}{N}$	Square Wave	0	Q_5, Q_8	Q_6, Q_7	Q_6, Q_7	Q_5, Q_8	–	–
$> \frac{240}{N}$	Quasi-Square Wave	$\frac{t_o}{2}\left(1 - \frac{240^2}{(NV_{pv})^2}\right)$	Q_5, Q_8	Q_6, Q_7	Q_6, Q_7	Q_5, Q_8	Q_5, Q_7 after Negative State	$Q_1, Q_2, Q_3, Q_4, Q_6, Q_8$
							Q_6, Q_8 after Positive State	$Q_1, Q_2, Q_3, Q_4, Q_5, Q_7$

Table. Summary of Switching

Operating Principle – *Simulated Results*

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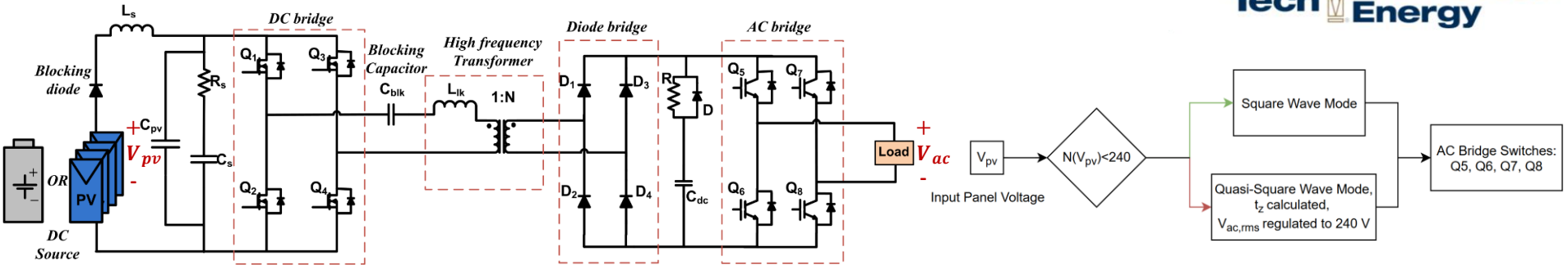
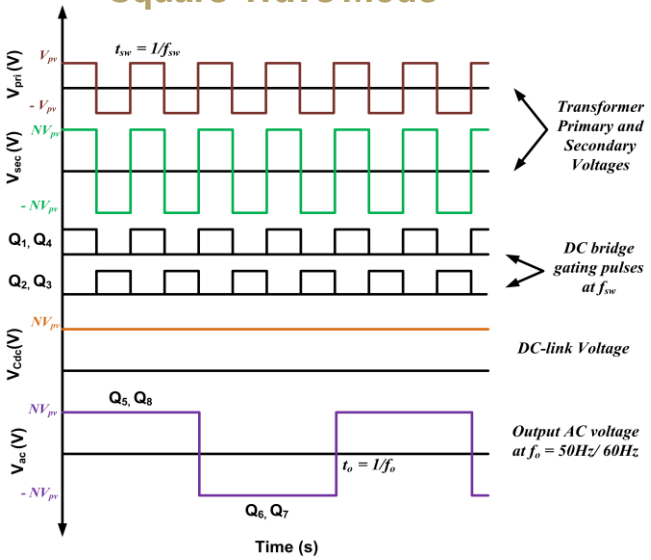
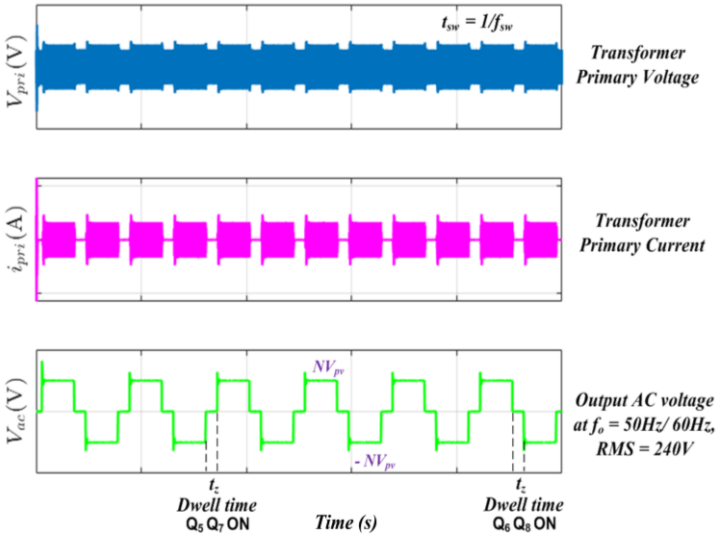


Square-Wave Mode



Quasi-Square Wave Mode



Simulation Results – *Irradiance Step*

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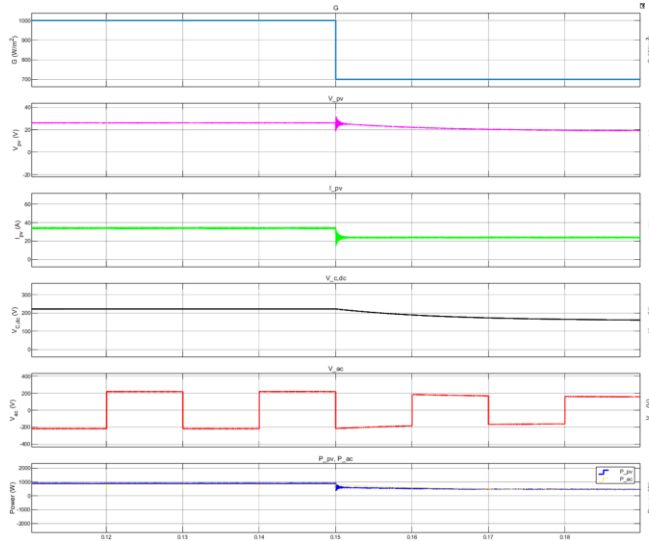
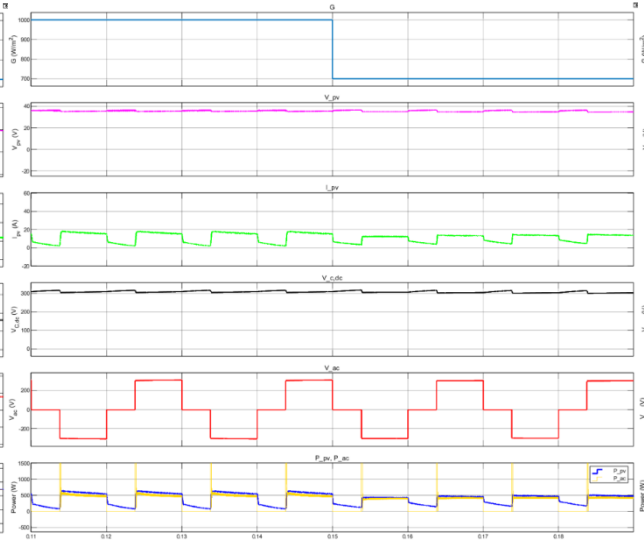
✓ **Transient Behavior**

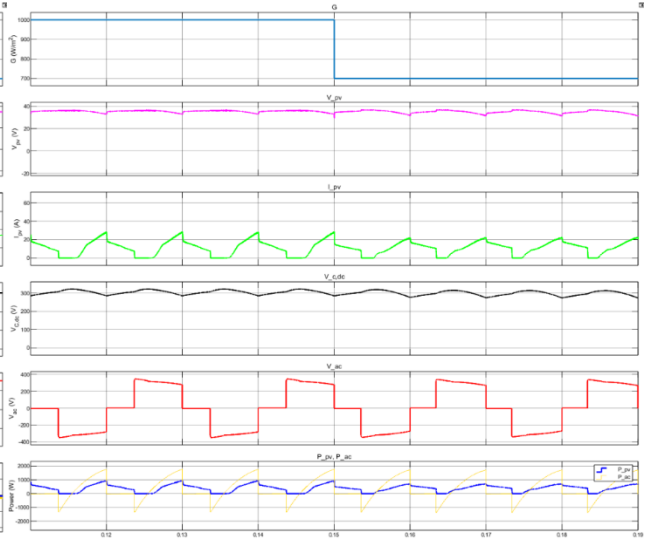
- Irradiance Step: G = 1000W/m^2 → G = 700 W/m^2
- Converter output is stable under transient irradiance conditions



Resistive (57.6Ω) Load ≈ 1kW

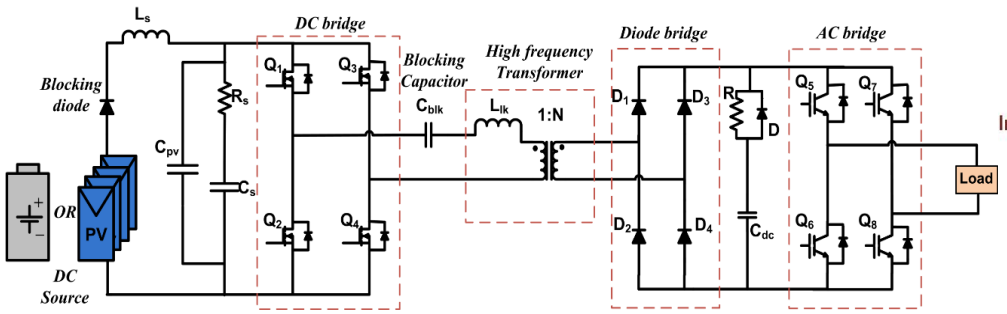


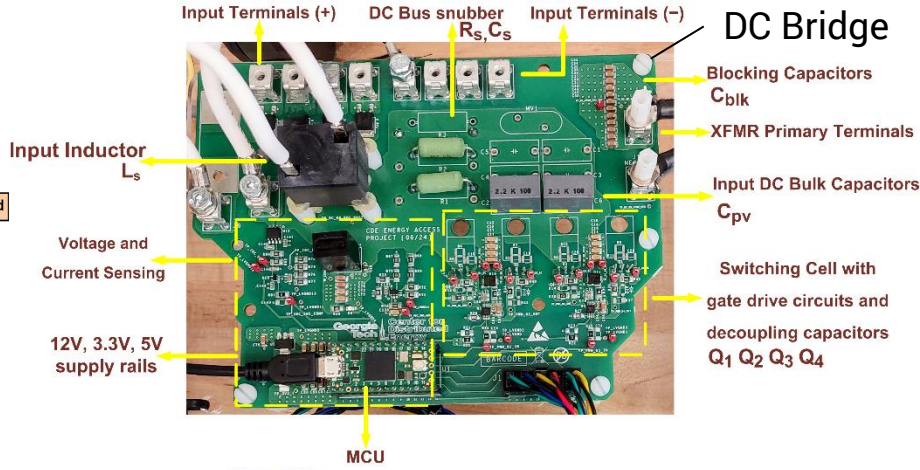
Rectified RC (250Ω, 470uF) Load



0.3pF RL (20Ω, 68mH) Load

Hardware Prototype – *Overview & Parameters*





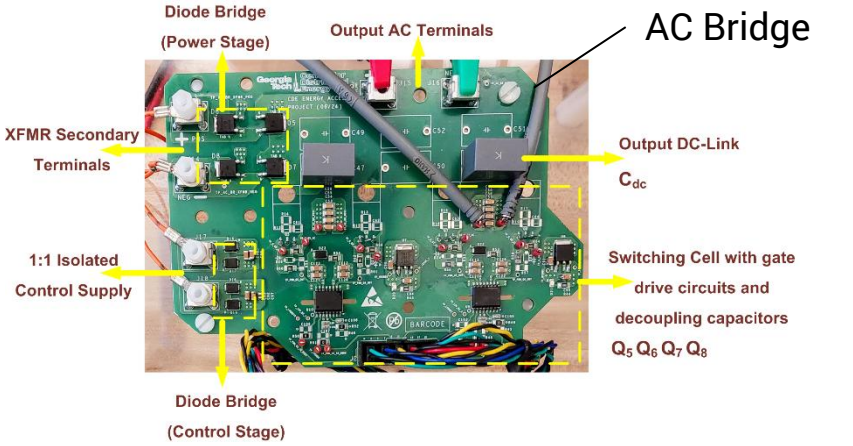
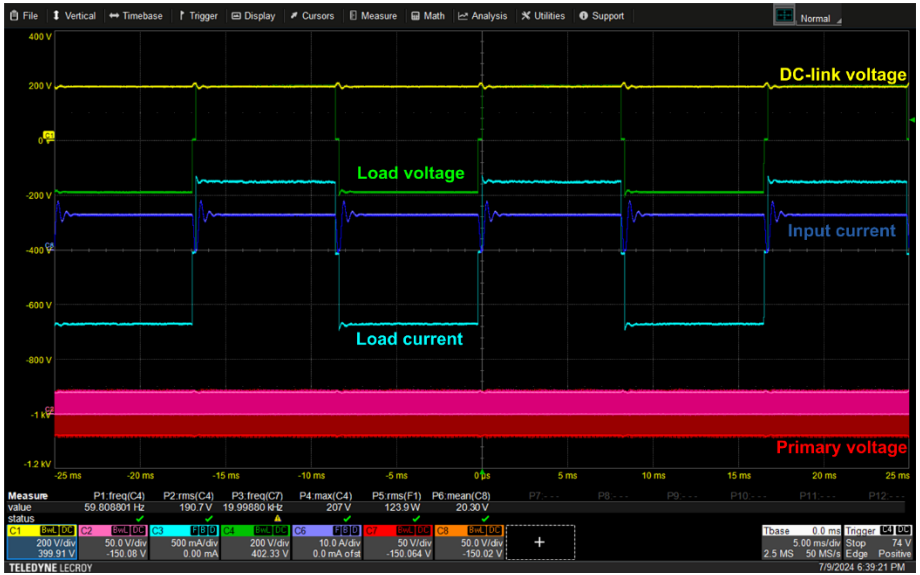


Table. Hardware prototype system parameters.

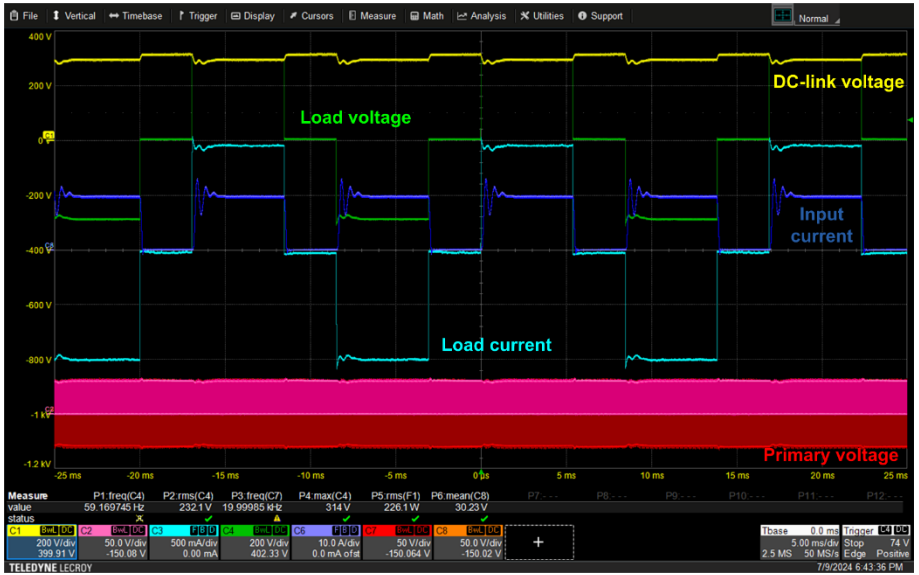
Param.	Value	Param.	Value
f_{sw}	20kHz	P_{rated}	1kW
f_o	50/60Hz	Diode V_{fwd}	1.38V
XFMR		L_s	10 uH
L_m	900 uH	C_{pv}	4.4 uF
N	10	R_s	0.5 Ω
L_{lk}	150 nH	C_{dc}	10 uF

Param.	Value
MOSFET , $R_{ds,on}$	1.7 mΩ
IGBT $V_{ce,sat}$	1.5V

Hardware Validation – *Resistive Load*



V_{in} = 20V



V_{in} = 30V

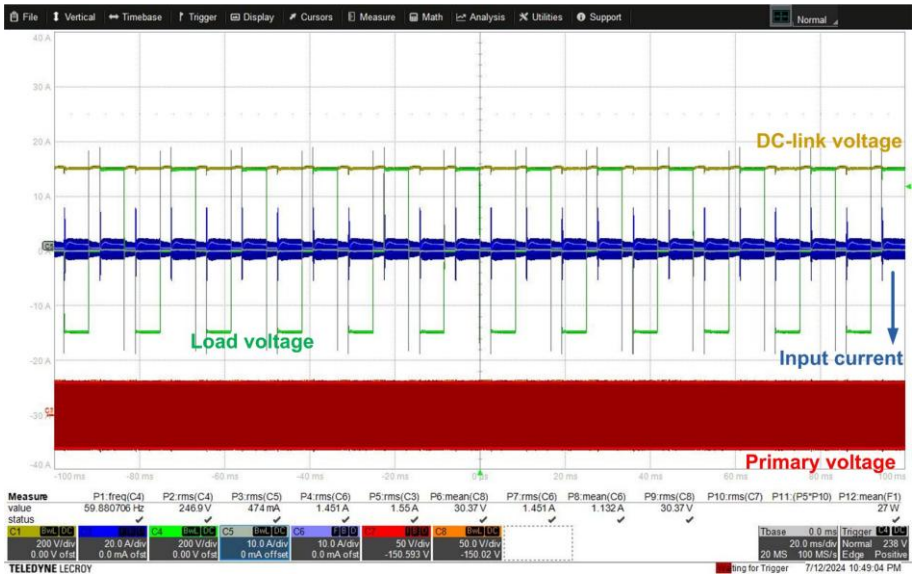
Load Parameters

- P_{peak} ≈190 W @ 240V RMS
- R_{load} = 302Ω

□Load Voltage
□Load Current
□DC-Link Voltage
□Input Current
□Primary Voltage

Hardware Validation – *Electronic Load*

V_{in} = 25V



V_{in} = 30V

Load Parameters

- $P_{peak} \approx 30$ W @ 240V RMS
- $I_{load} = 1.5A$

- Load Voltage
- Load Current
- DC-Link Voltage
- Primary Voltage
- Input Current