Test Report: PMP31276

288W PFC, LLC and Bidirectional Battery Charger Reference Design

Description

This reference design is an AC/DC battery-backup charger with two outputs: system and battery. A 4-SW bidirectional buck-boost charges the battery and supplies system load. An optional microcontroller disables main power sections, reducing stand-by power while collecting parameters for telemetry.

Resources

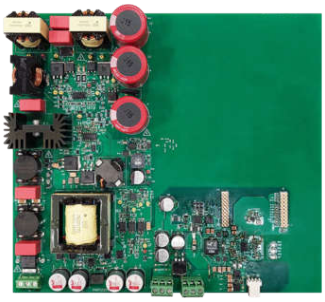
PMP31276	Design Folder
UCC28065, TLV1812	Product Folder
LM4040, UCC256613	Product Folder
UCC24624, ATL431	Product Folder
BQ25751, CSD18531	Product Folder
UCC28910, TPS560430	Product Folder

Features

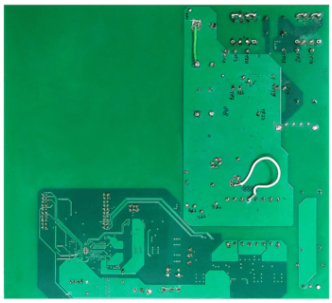
- Achieves 91.8% efficiency at 230V_{AC} with all power stages on (PFC, LLC and battery charger)
- Good option for backup supply in alarm panels and uninterruptible power delivery
- Interleaving modulation in the PFC allows input filter and output capacitor ripple-current reduction, while minimizing the height thanks to two-phase power stage
- The LLC stage enhances light load efficiency (standby power and audible noise) thanks to high and low frequency burst mode scheme
- The third stage provides battery management and leverages power path and bidirectional power flow to achieve the highest efficiency possible, while charging the battery and supplying system power

Applications

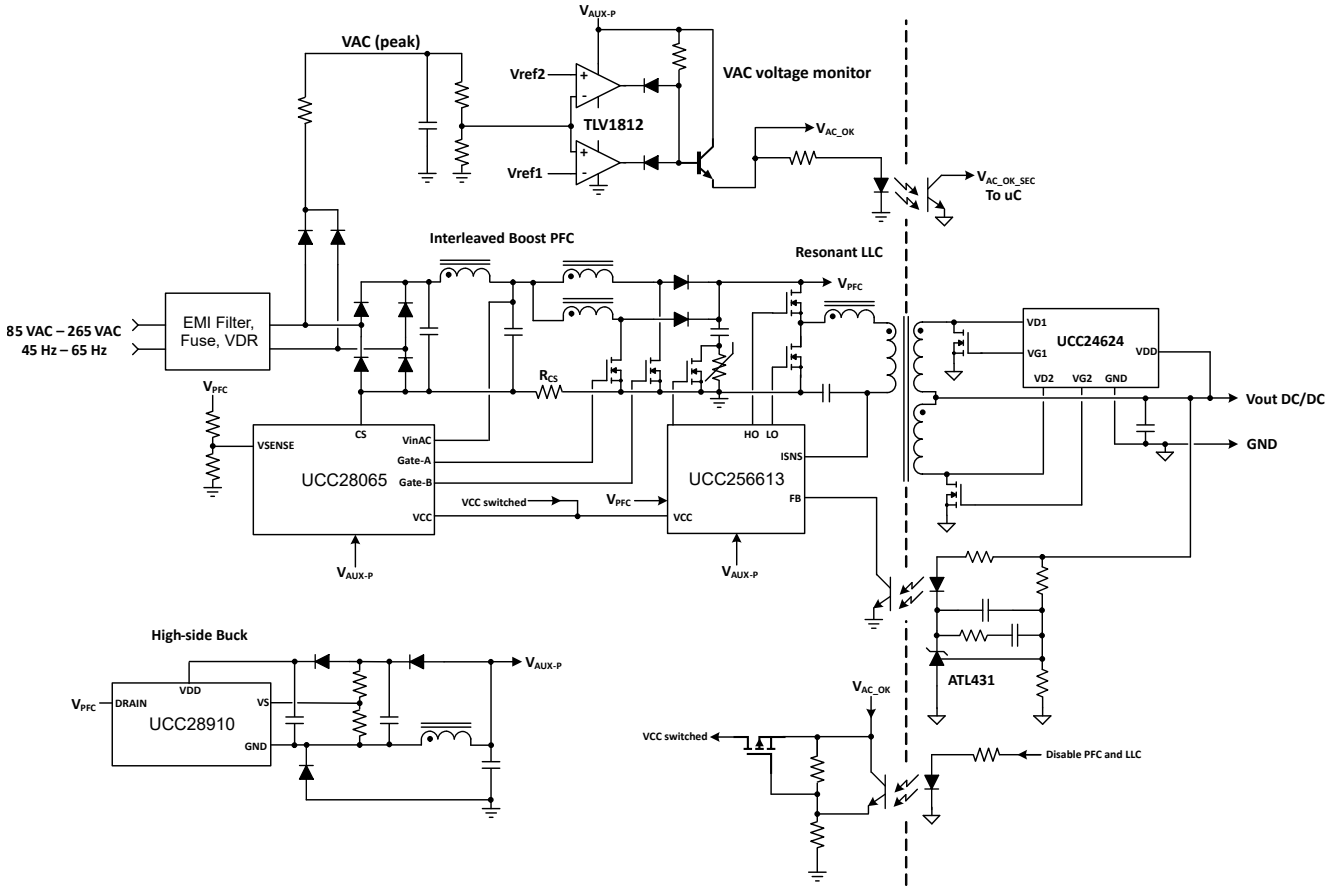
- Fire alarm control panel (FACP)



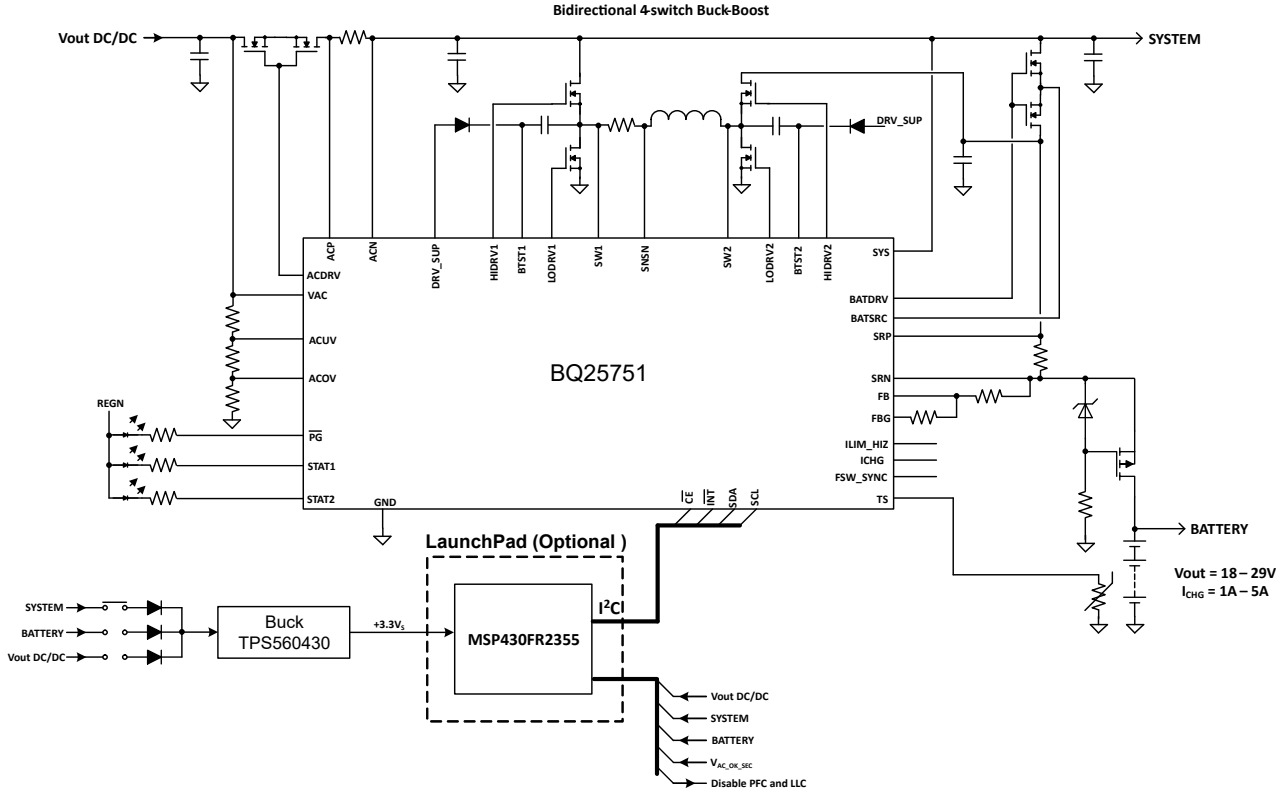
Top View



Bottom view



AC/DC Block diagram



Battery Charger Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input voltage range	$85V_{AC}$ – $265V_{AC}$
Input voltage frequency	47Hz – 63Hz
System output voltage	24V
Battery output voltage	21.6V to 28V
System output current	12A
Battery output current	Nominal 2A, maximum 5A

1.2 Required Equipment

- AC source: California instruments 2001RP
- Digital power meter: Vitrek PA900
- Electronic load: HP 6063B
- Oscilloscope: LeCroy waverunner 64Xi-A
- Infrared thermal camera: Flir one edge pro
- True RMS multimeter: Metrahit pro

1.3 Considerations

All tests refer to ambient temperature of 25ºC, the board placed horizontal on the bench, no forced air flow.

1.4 Safety Considerations

High Voltage

Hot Surface

1.5 Dimensions

Board size:

AC/DC: 100mm × 203mm × 2mm (W × L × H)

Battery charger: 105mm × 75mm × 15mm (W × L × H)

1.6 Test Setup

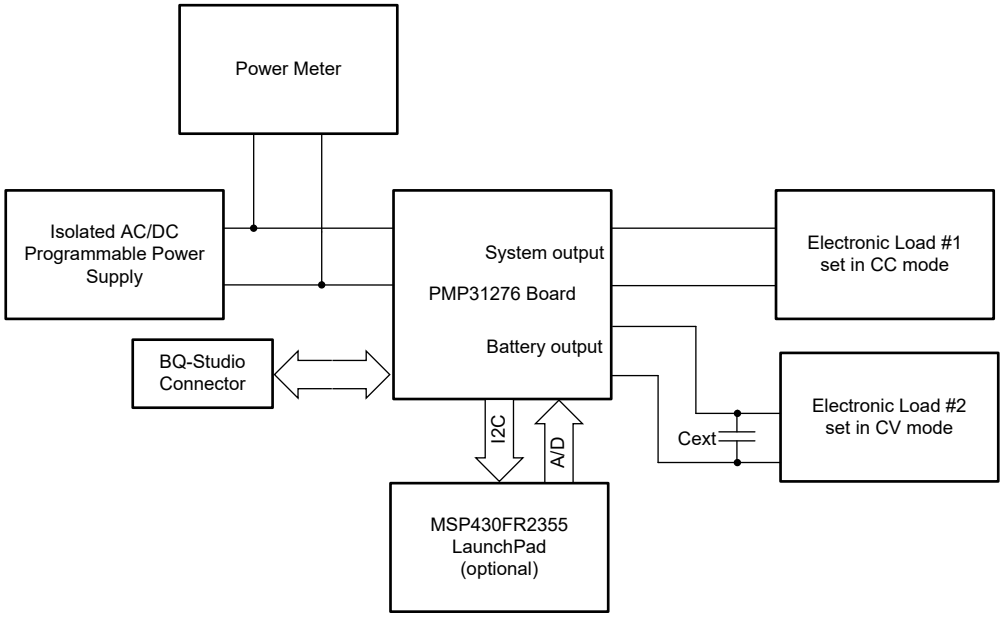


Figure 1-1. Test Setup

2 Testing and Results

2.1 Efficiency Graphs

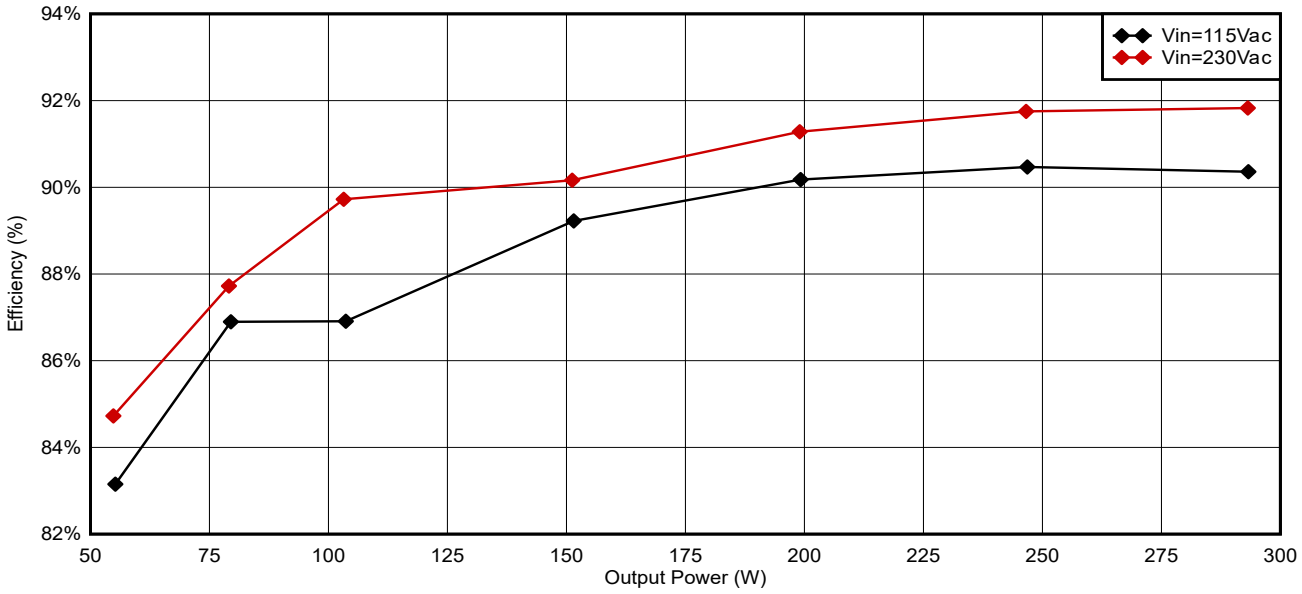


Figure 2-1. Plug-to-plug Efficiency Graph versus Input VAC and Load Power

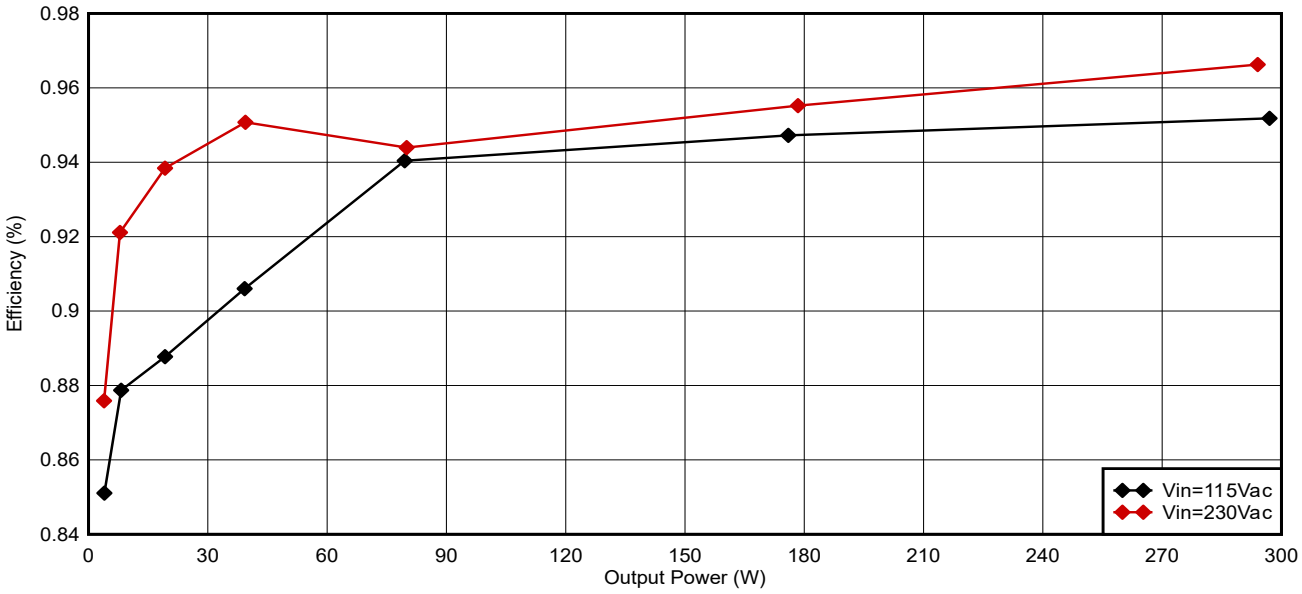


Figure 2-2. PFC Stage Efficiency versus Load Power and Input V_{AC}

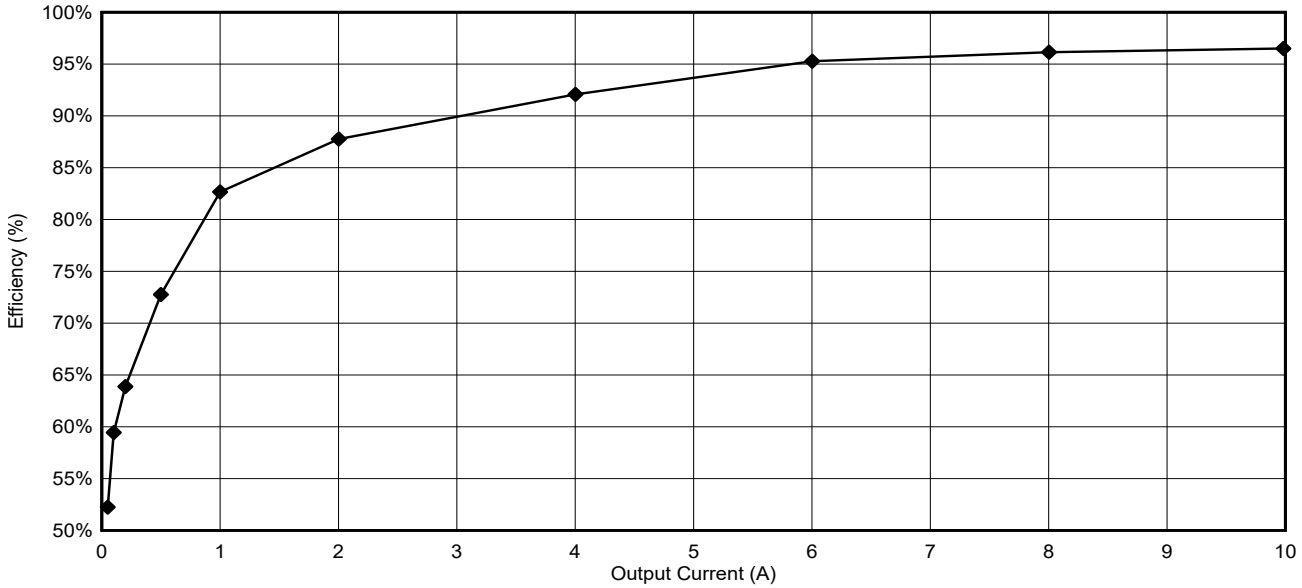


Figure 2-3. LLC Stage Efficiency versus Load Current

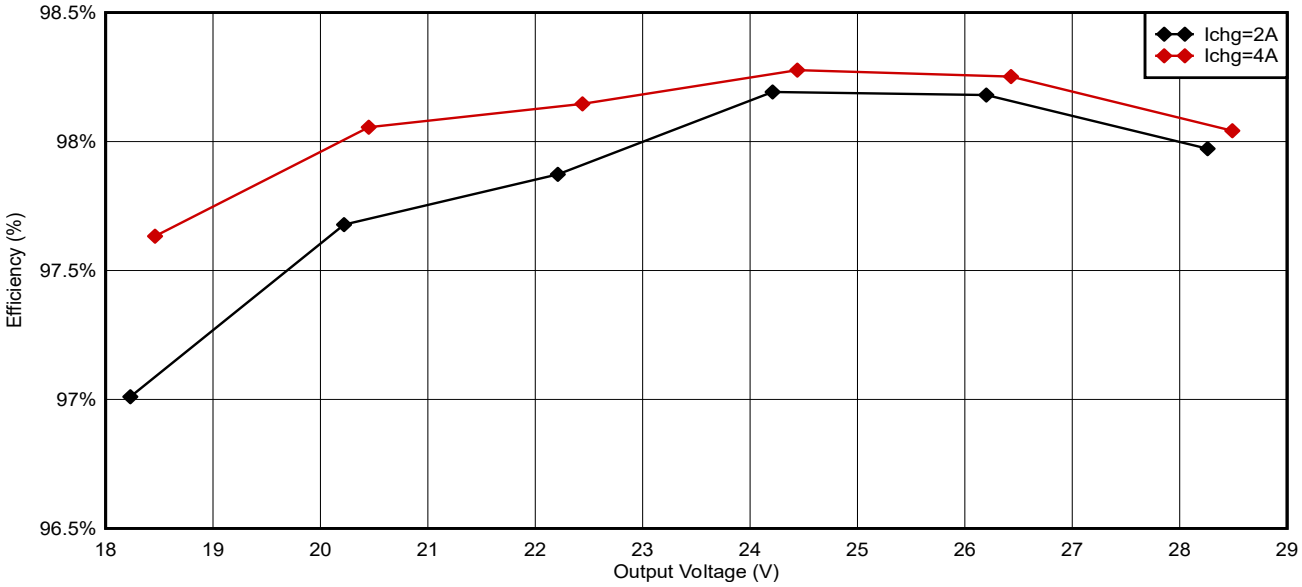


Figure 2-4. Buck-Boost Efficiency versus Battery Voltage and Charging Current

2.2 Efficiency Data

Efficiency data are shown in Table 2-1 and Table 2-2

Table 2-1. Plug-to- plug Efficiency Data at 230VAC, Constant Charging Current = 2A

Input Power (W)	System V_{OUT} (V)	Battery V_{OUT} (V)	System I_{OUT} (A)	Battery I_{OUT} (A)	Output Power (W)	Efficiency (%)
64.69	24.08	26.92	0.000	2.036	54.81	84.73
90.16	24.05	26.96	1.004	2.038	79.09	87.72
115.02	24.02	26.99	2.003	2.041	103.20	89.72
167.70	23.96	27.06	4.000	2.046	151.20	90.16
218.02	23.89	27.13	6.000	2.052	199.01	91.28
268.75	23.82	27.22	8.000	2.058	246.58	91.75
319.24	23.75	27.31	9.970	2.064	293.16	91.83

Table 2-2. Plug-to-plug Efficiency Data at 115VAC, Constant Charging Current = 2A

Input Power (W)	System V_{OUT} (V)	Battery V_{OUT} (V)	System I_{OUT} (A)	Battery I_{OUT} (A)	Output Power (W)	Efficiency (%)
64.42	24.07	27.14	0.000	2.035	55.23	83.15
91.49	24.04	27.18	1.004	2.037	79.50	86.90
119.26	24.01	27.21	2.005	2.040	103.65	86.91
169.84	23.93	27.27	4.001	2.046	151.54	89.22
220.90	23.89	27.34	5.990	2.052	199.20	90.18
272.83	23.82	27.34	8.000	2.058	246.83	90.47
324.57	23.75	27.37	9.970	2.064	293.28	90.36

2.3 Thermal Images

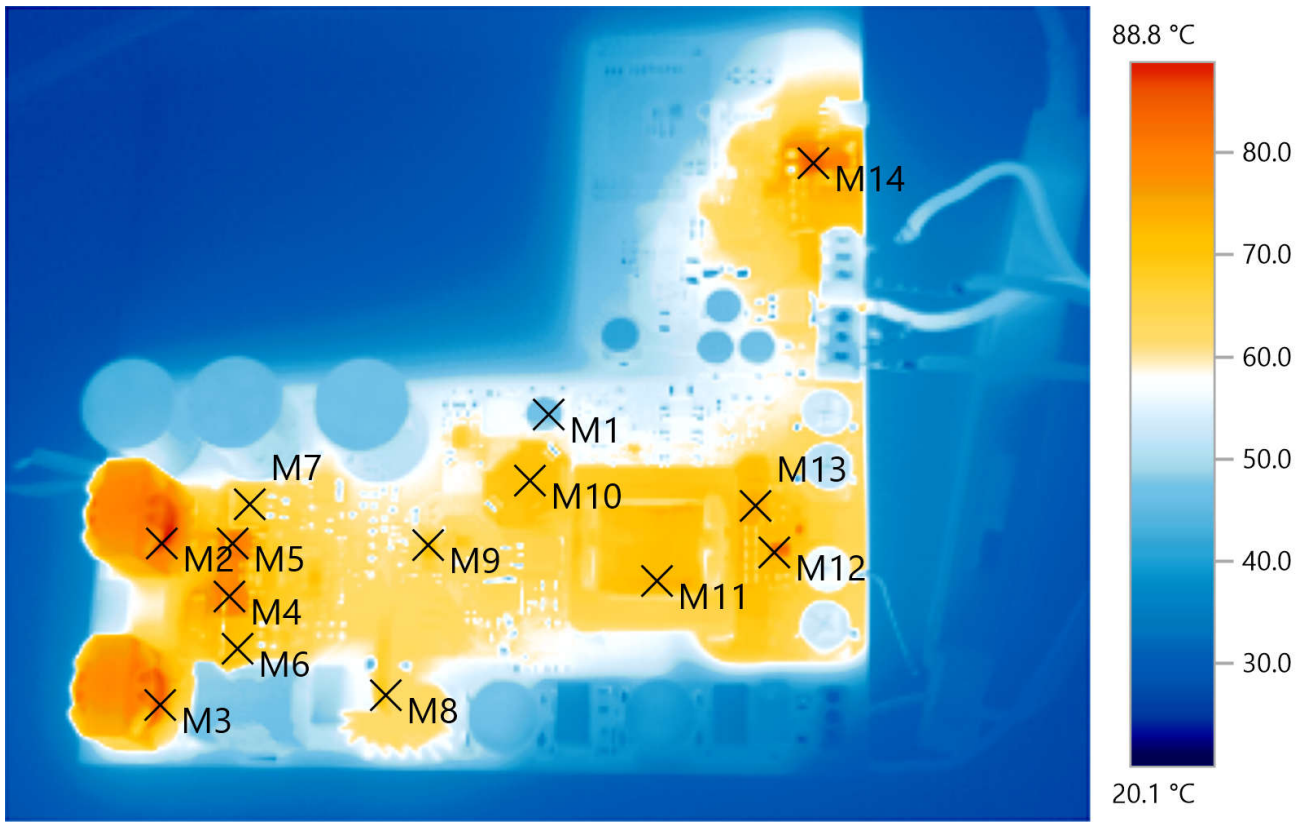


Figure 2-5. Thermal Image at Maximum Power, V_{IN} = 115V_{AC}, 30 Minutes Running, T_{amb} = 23°C

Measurement Objects	Temperature (°C)	Emission	Refl. Temp (°C)	Remarks
M1	42.5	0.95	20.0	Center Spot
M2	87.3	0.95	20.0	L1
M3	83.5	0.95	20.0	L5
M4	76.9	0.95	20.0	D8
M5	78.8	0.95	20.0	D1
M6	67,6	0.95	20.0	Q3
M7	63.7	0.95	20.0	Q1
M8	63.1	0.95	20.0	D3 heat sink
M9	67.3	0.95	20.0	U7
M10	66.5	0.95	20.0	L6
M11	69.9	0.95	20.0	T1
M12	78.6	0.95	20.0	U6
M13	71	0.95	20.0	Q11
M14	82.9	0.95	20.0	Q16

2.4 Bode Plot

The Bode plot of the LLC converter is shown in Figure 2-6. The crossover frequency at 10A load current is 2.789kHz, phase margin 102.9° and gain margin 10.36dB.

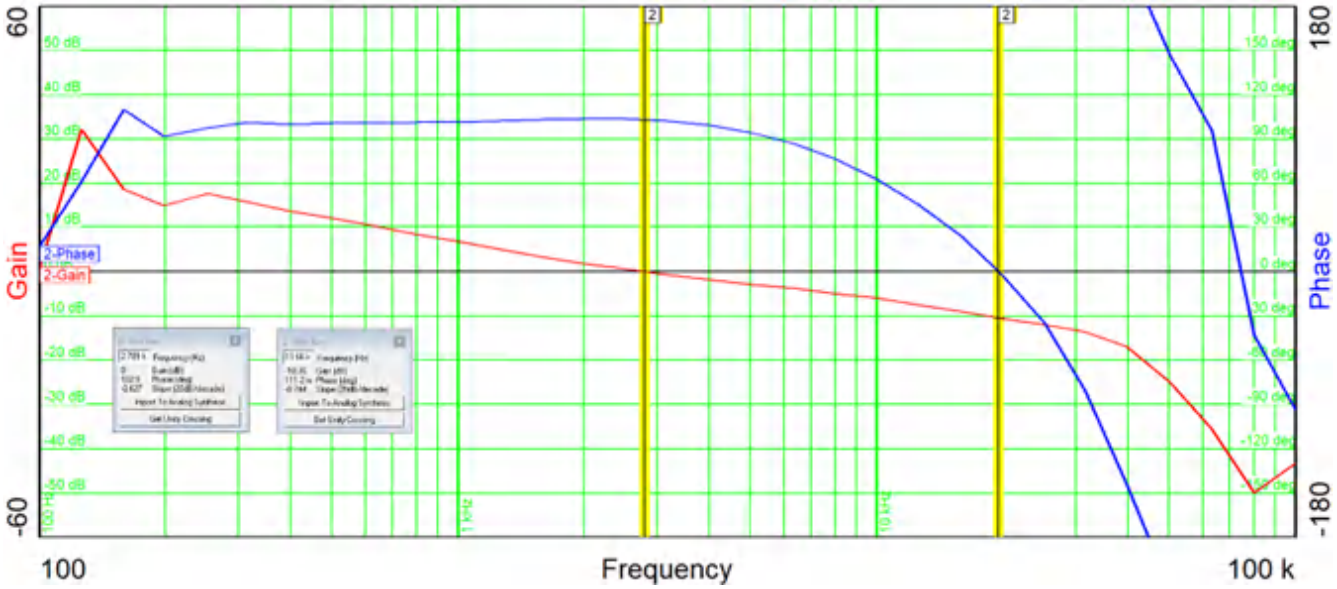


Figure 2-6. Bode Plot of the LLC Converter at 10A Load Current

3 Waveforms

3.1 Switching

The switching behavior of PFC and LLC stages are shown in Figure 3-1 through Figure 3-4.

Conditions: V_{IN} = 230V_{AC}, Battery voltage = 28V, Charging current = 0A, System output current = 10A

C1: V_{DS} of Q10, C2: V_{DS} of Q7SW pin of U2, C3: Resonant current (L6), C4: V_{DS} of Q1

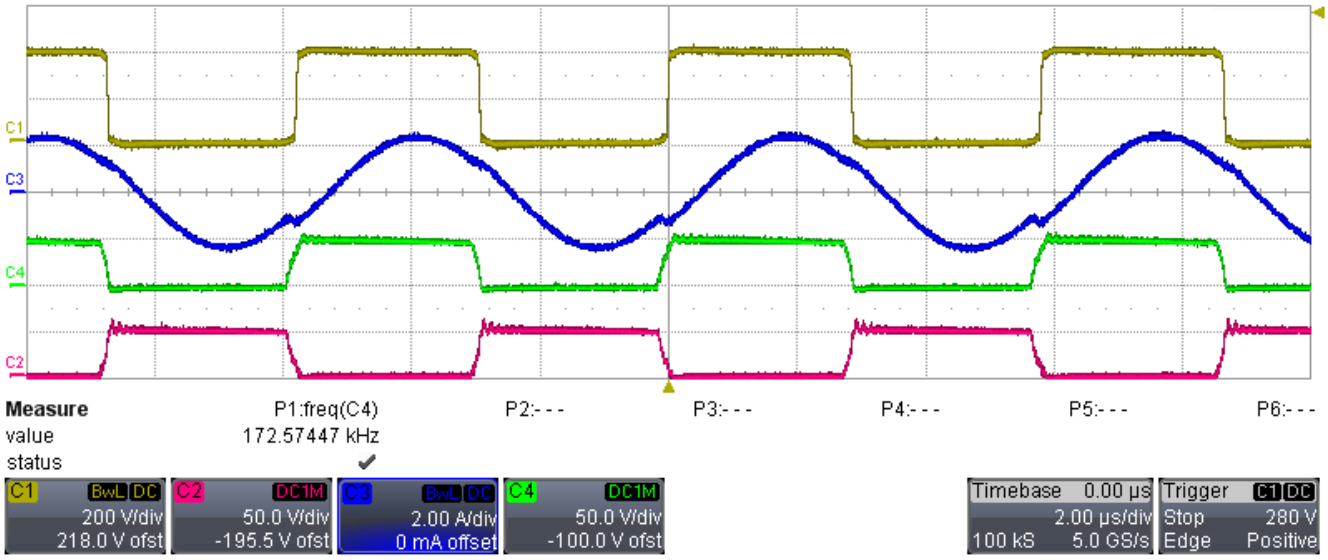


Figure 3-1. Switching Waveforms LLC Stage at 230V_{AC} and 10A System Load Current

C2: SW1 node, C4: SW2 node, C3: Battery current (AC coupling)

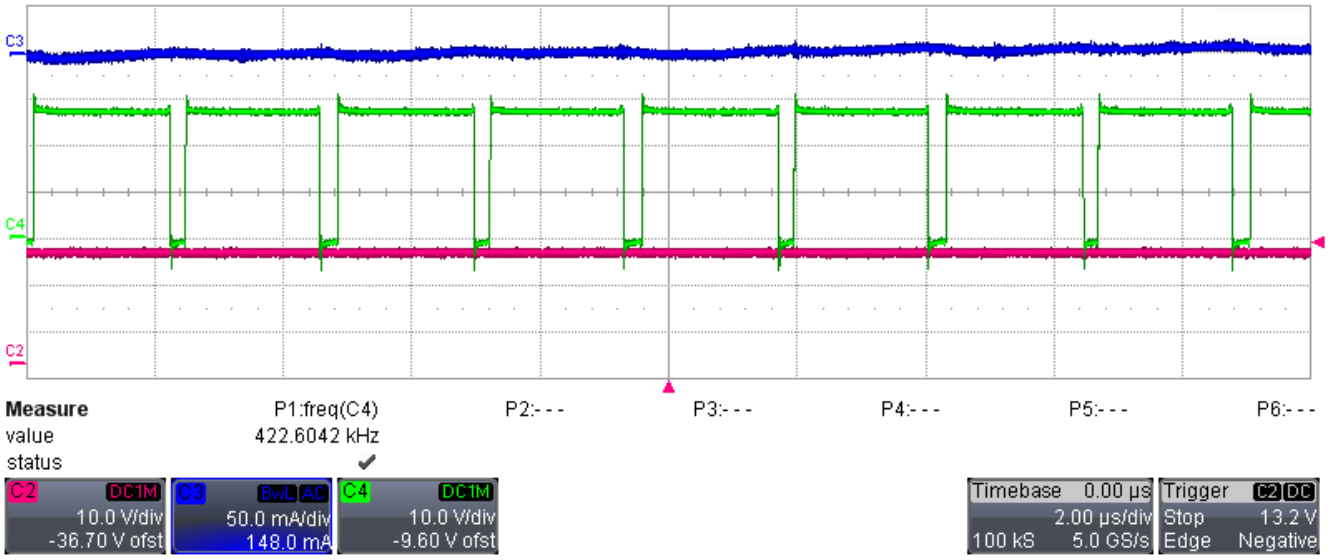


Figure 3-2. Switching Waveforms on 4-SW Buck-Boost Stage at 230V_{AC}, V_{BAT} = 27V, I_{CHG} = 2A and 1A System Current Load

C2: SW1 node, C4: SW2 node, C3: Battery current (AC coupling)

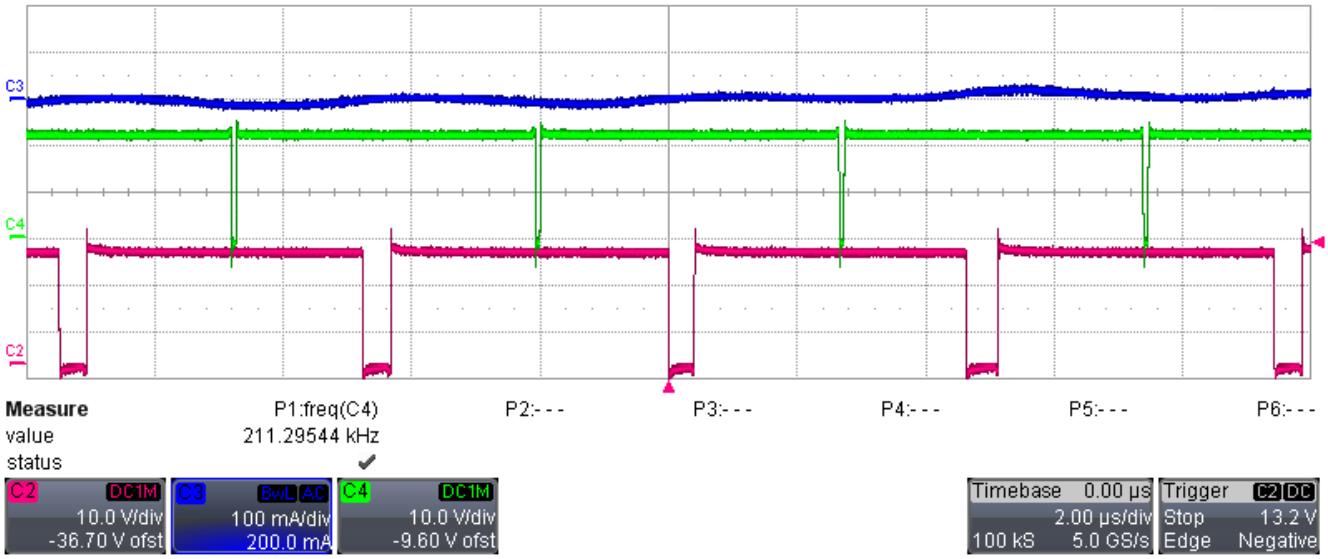


Figure 3-3. Switching Waveforms on 4-SW Buck-Boost Stage at 230V_{AC}, V_{BAT} = 22V, I_{CHG} = 2A and 1A System Current Load

C1: V_{DS} of Q3, C2: V_{DS} of Q1

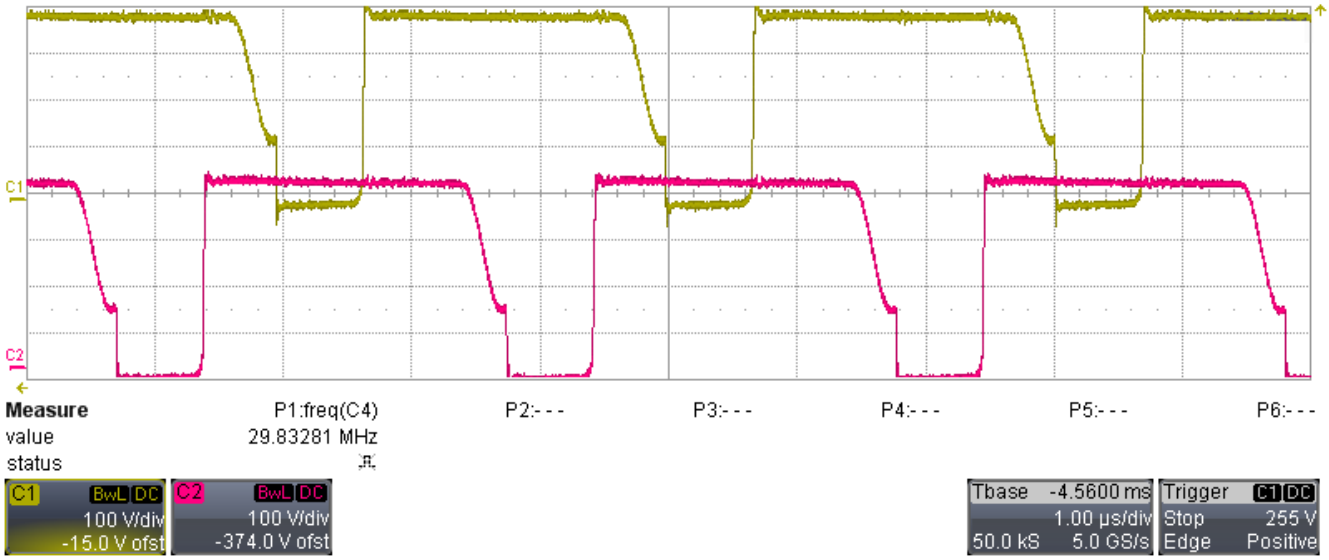


Figure 3-4. Switching Waveforms on PFC Stage at 230V_{AC}, V_{BAT} = 28V, I_{CHG} = 0A and 10A System Current Load

3.2 Output Voltage Ripple

Output ripple voltage is shown in Figure 3-5.

C2: Battery Voltage, C3: Battery Current, C4: System Voltage (AC Coupled, 20MHz Bandwidth Limit)

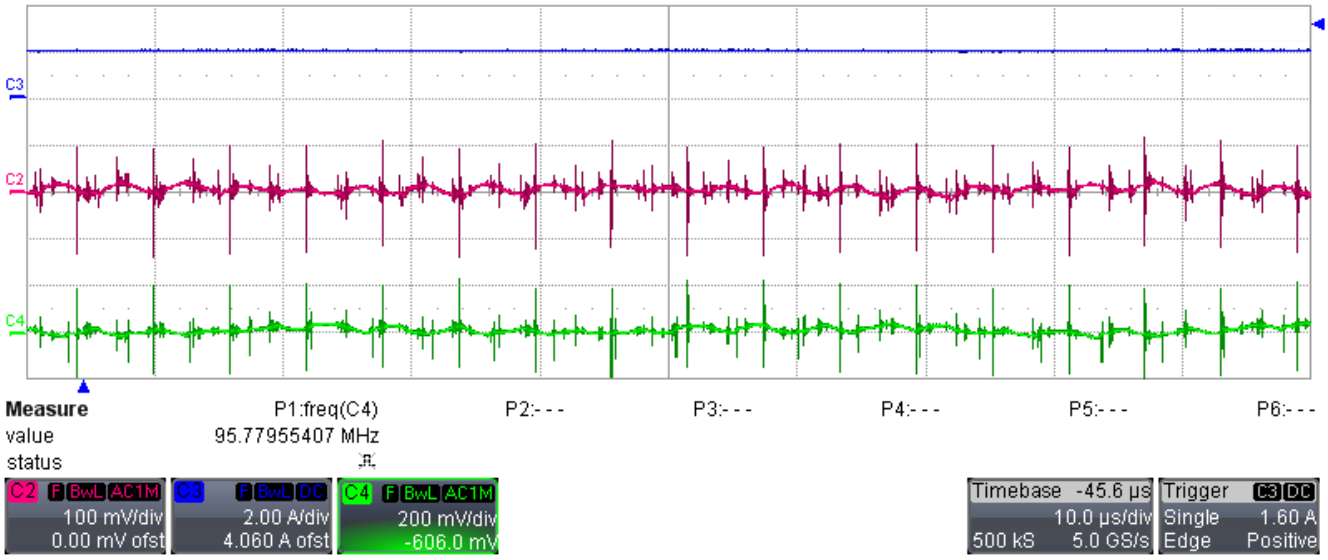


Figure 3-5. Voltage Ripple on Battery and System Output

3.3 Load Transients

Load transient response is shown in Figure 3-6.

C3: LLC stage output voltage (DC coupled), C4: LLC stage output current (AC coupled), 20MHz bandwidth limit for both waveforms

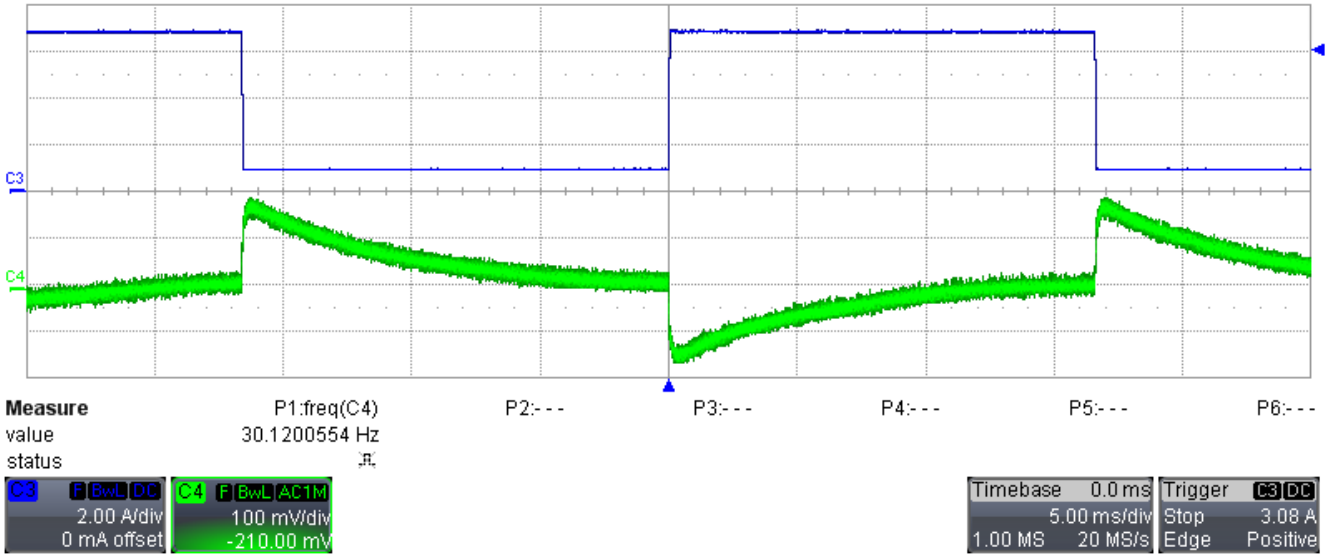


Figure 3-6. Transient Response for the LLC Stage with Current Switched Between 1A and 7A

3.4 Start-up Sequence

Start-up behavior is shown in Figure 3-7 through Figure 3-9.

C1: PFC output voltage, C2: LLC stage output voltage, C3: PFC input current, C4: battery voltage

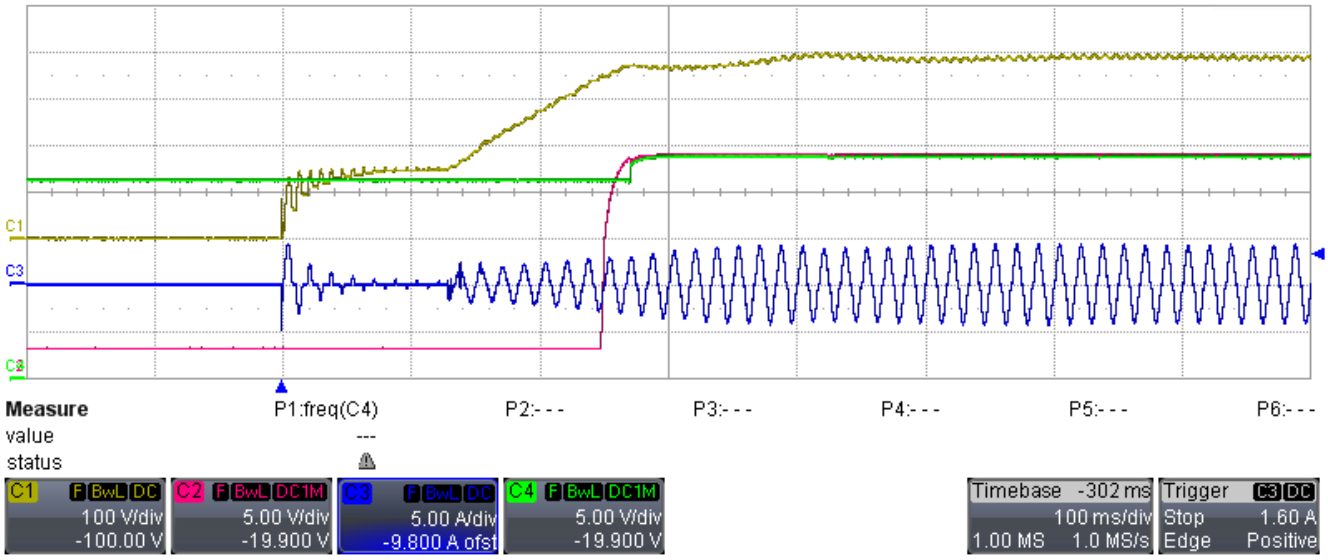


Figure 3-7. Startup at 115V_{AC}, V_{BAT} = 22V, I_{SYS} = 10A

C1: PFC output voltage, C2: LLC stage output voltage, C3: PFC input current, C4: battery voltage

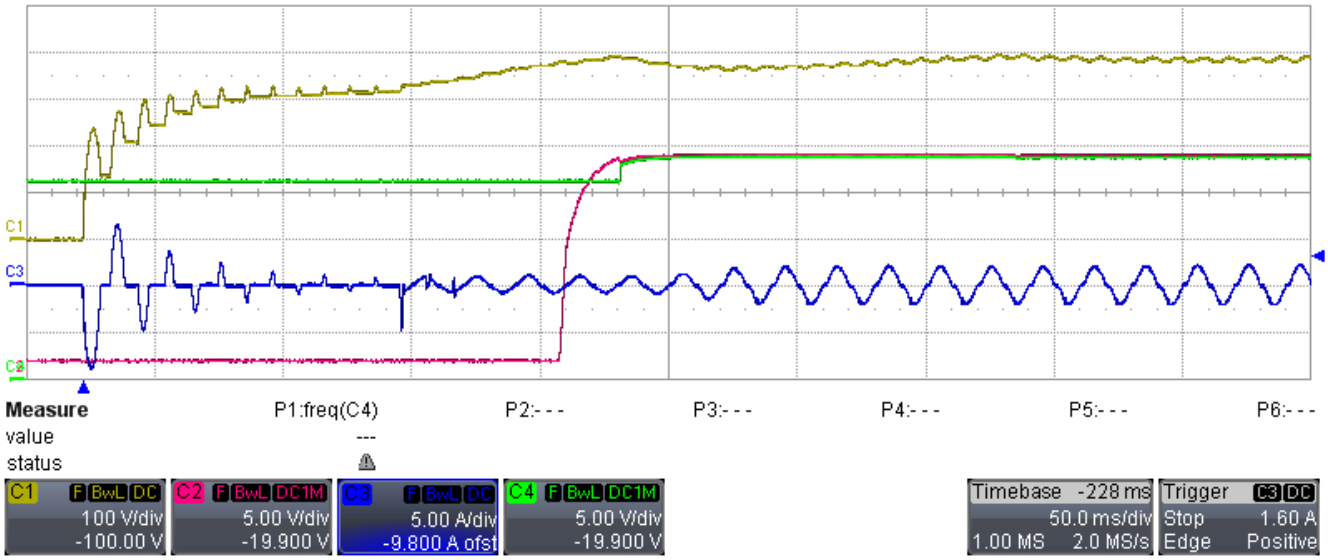


Figure 3-8. Startup at 230V_{AC}, V_{BAT} = 22V, I_{SYS} = 10A

C1: PFC output voltage, C2: LLC stage output voltage, C3: battery charging current, C4: battery voltage

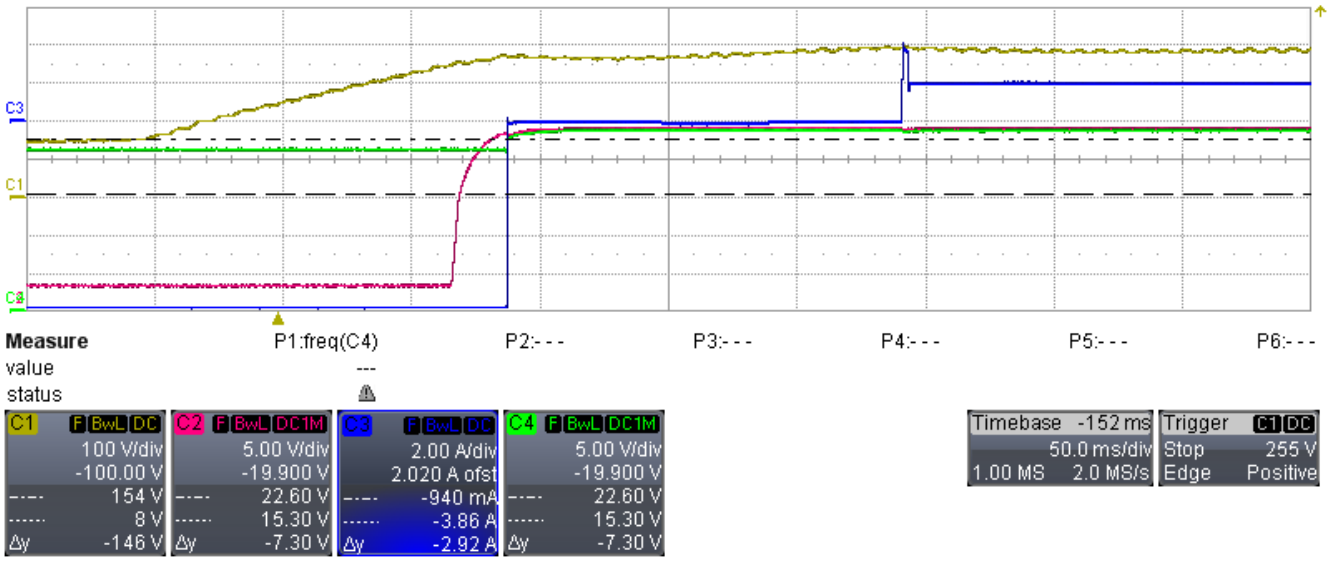


Figure 3-9. Startup at 115V_{AC}, V_{BAT} = 22V, I_{SYS} = 10A

3.5 Shut-down Sequence

AC input source turns off while the converter runs.

C1: PFC output voltage, C2: LLC stage output voltage, C3: battery charging current, C4: battery voltage

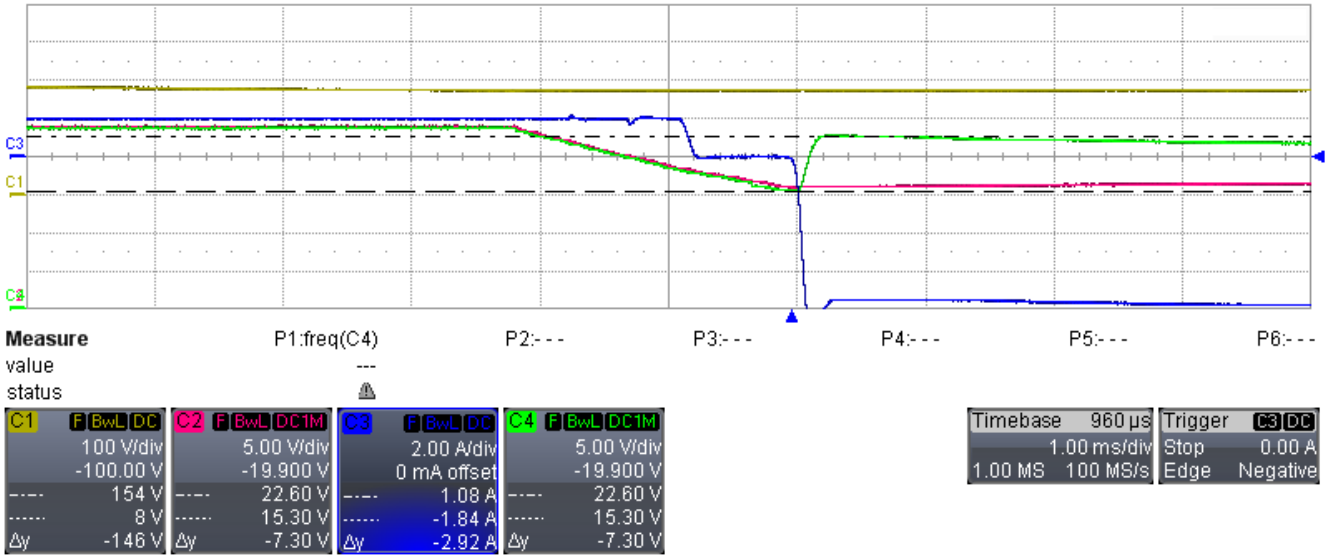


Figure 3-10. Shutdown and Battery Backup at 115V_{AC}, V_{BAT} = 22V, I_{SYS} = 8A

3.6 AC Waveforms

AC input source current and voltages are shown in Figure 3-11 and Figure 3-12.

C1: PFC output voltage, C2: Input AC voltage, C3: Input AC current, C4: System voltage

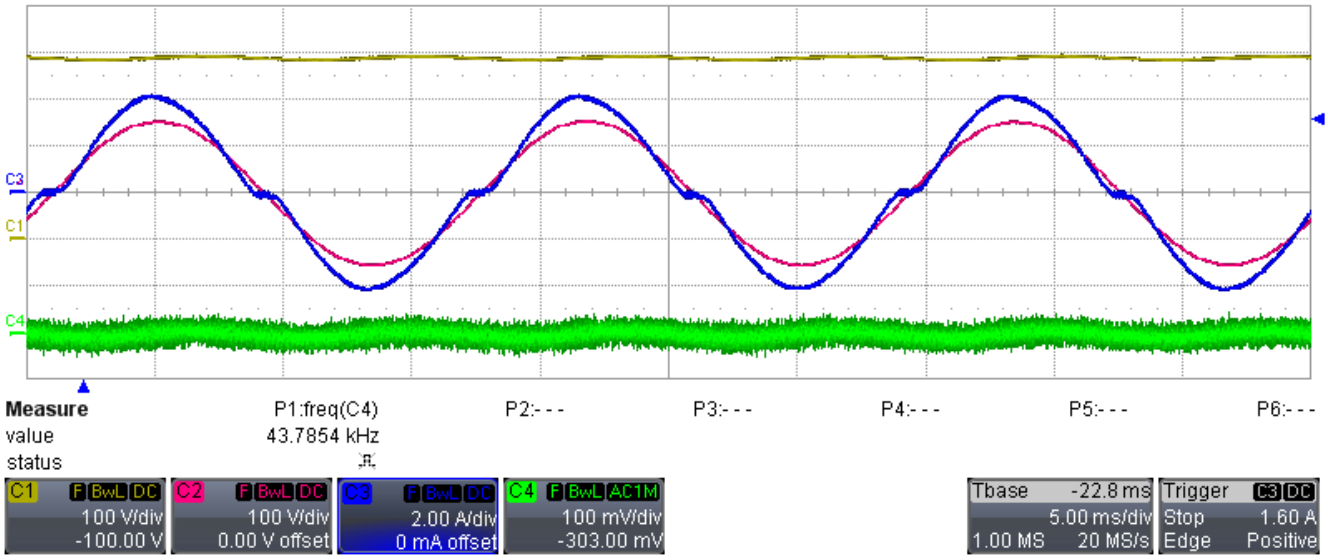


Figure 3-11. Input AC Voltage and Current of the PFC Stage at 115V_{AC} and 10A System Load Current

C1: PFC output voltage, C2: Input AC voltage, C3: Input AC current, C4: System voltage

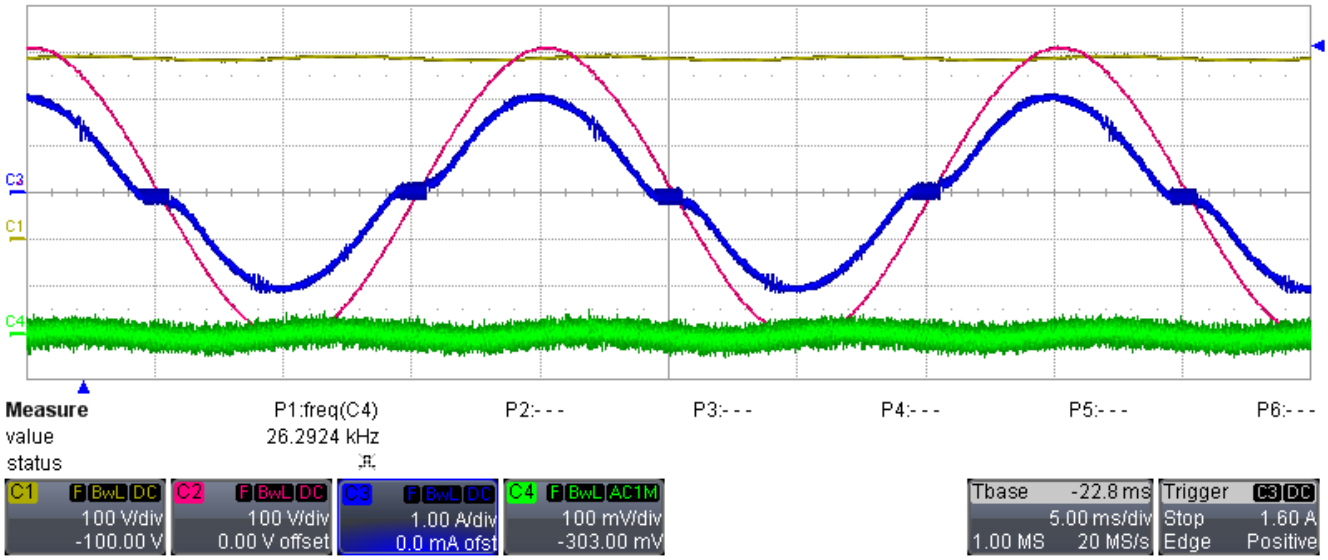


Figure 3-12. Input AC Voltage and Current of the PFC Stage at 230V_{AC} and 10A System Load Current

4 Static Regulation

The static regulation performance is shown in Figure 4-1 and Figure 4-7.

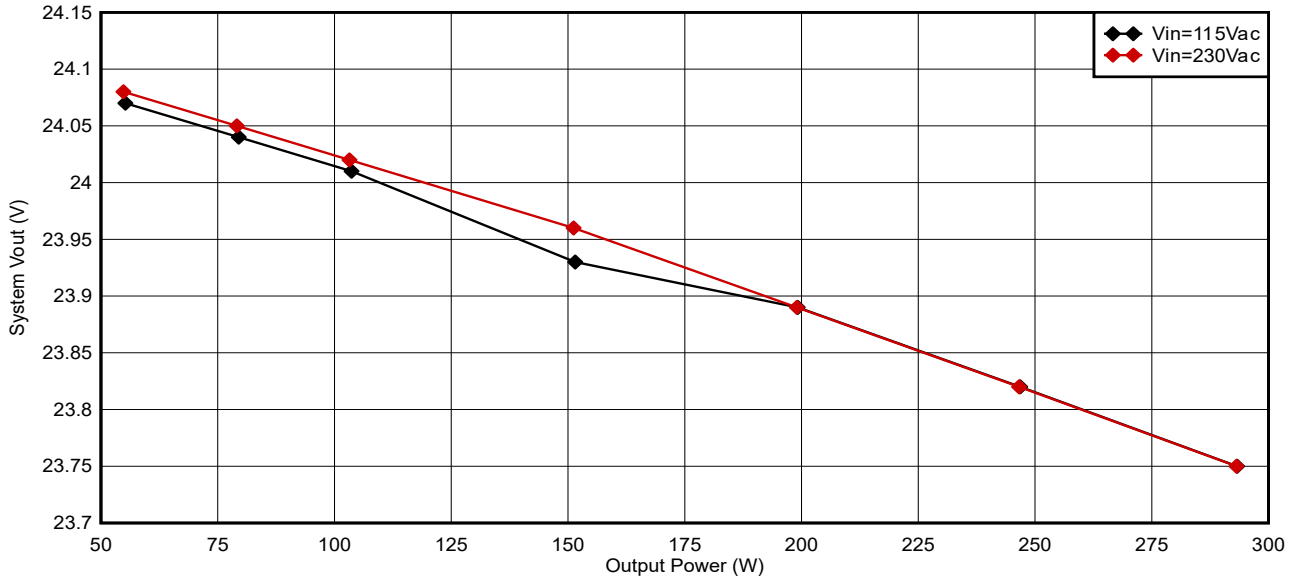


Figure 4-1. System Output Voltage Static Regulation versus Power and Input V_{AC}

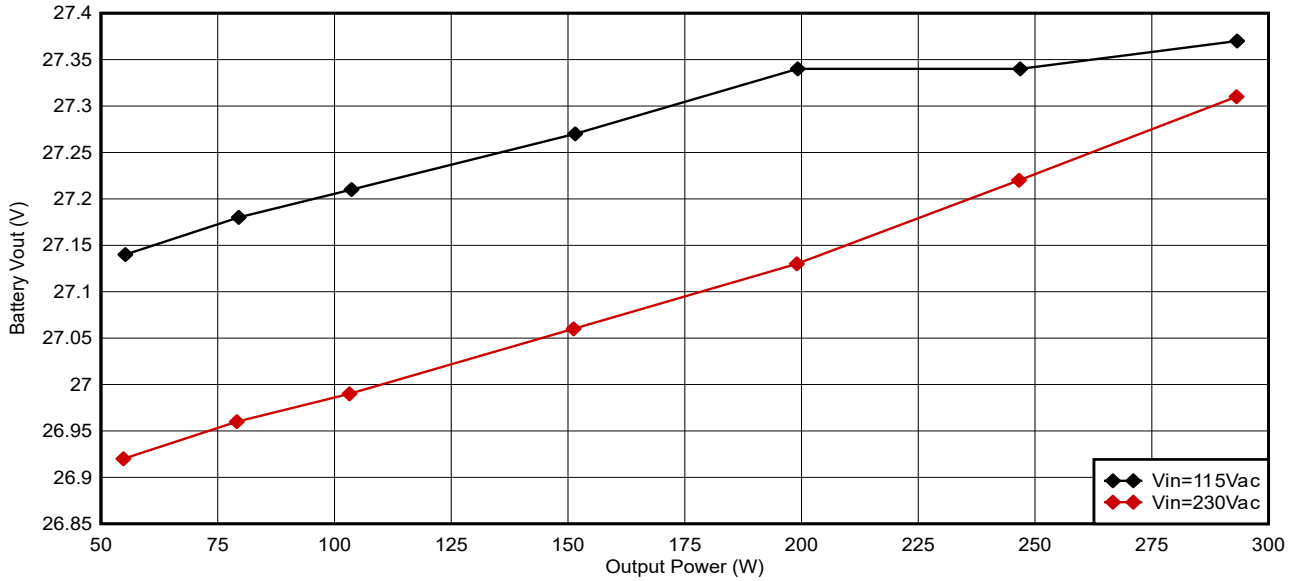


Figure 4-2. Battery Voltage Static Regulation versus Power and Input V_{AC}

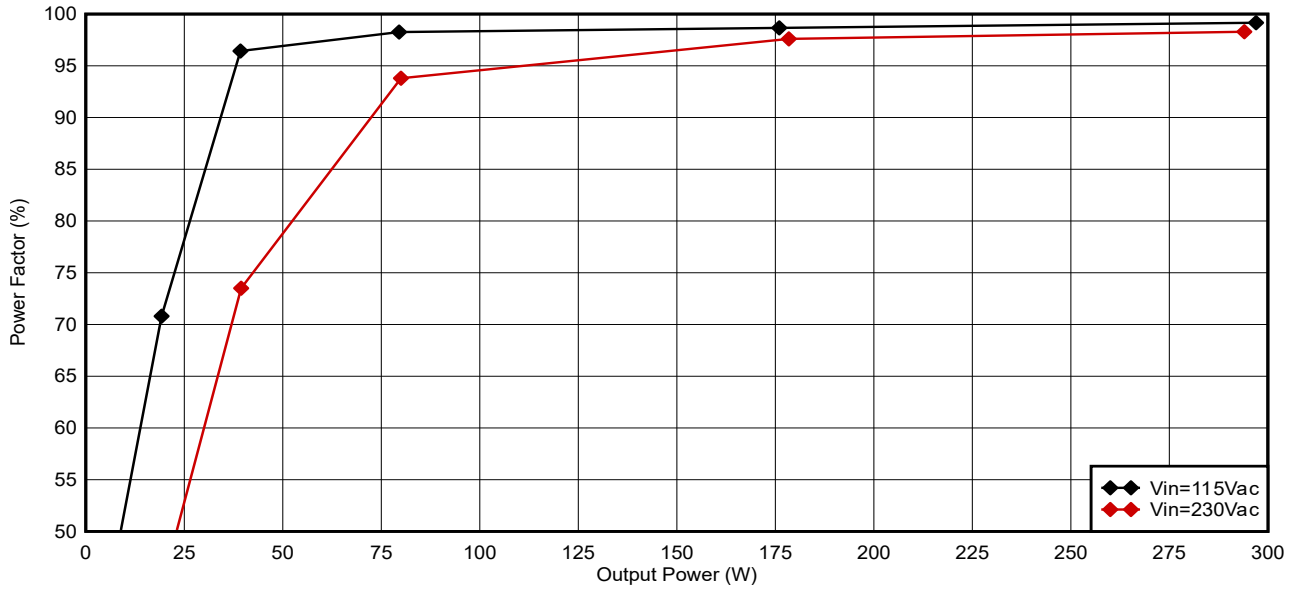


Figure 4-3. Power Factor of the PFC Stage versus Power and V_{AC}

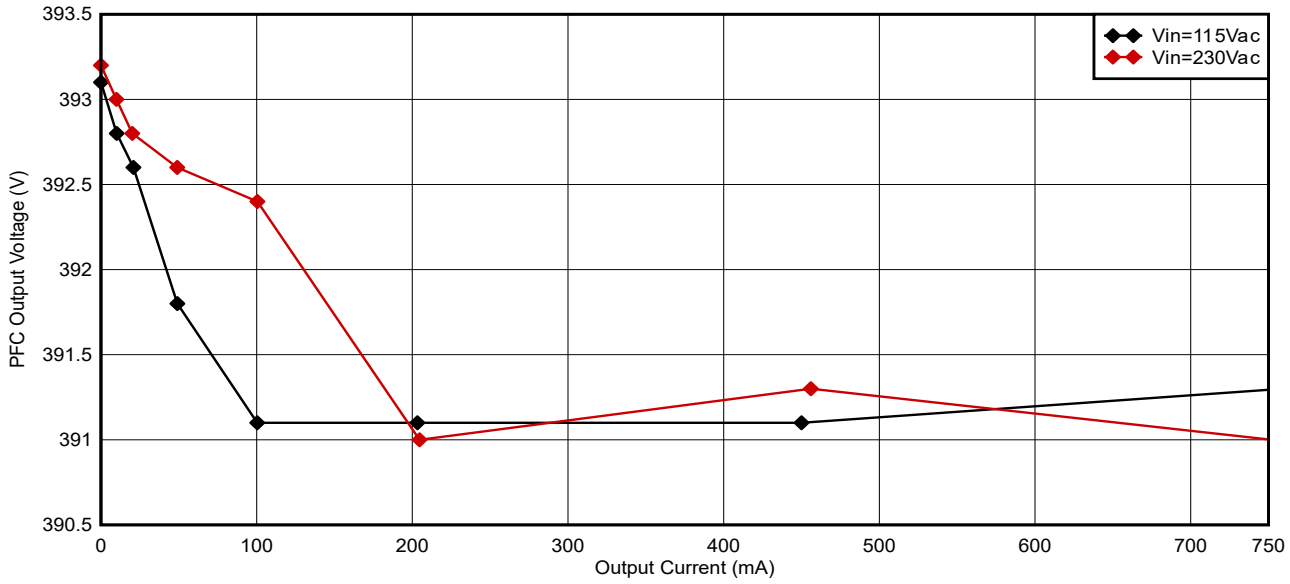


Figure 4-4. PFC Stage Static Voltage Regulation versus Output Current and V_{AC}

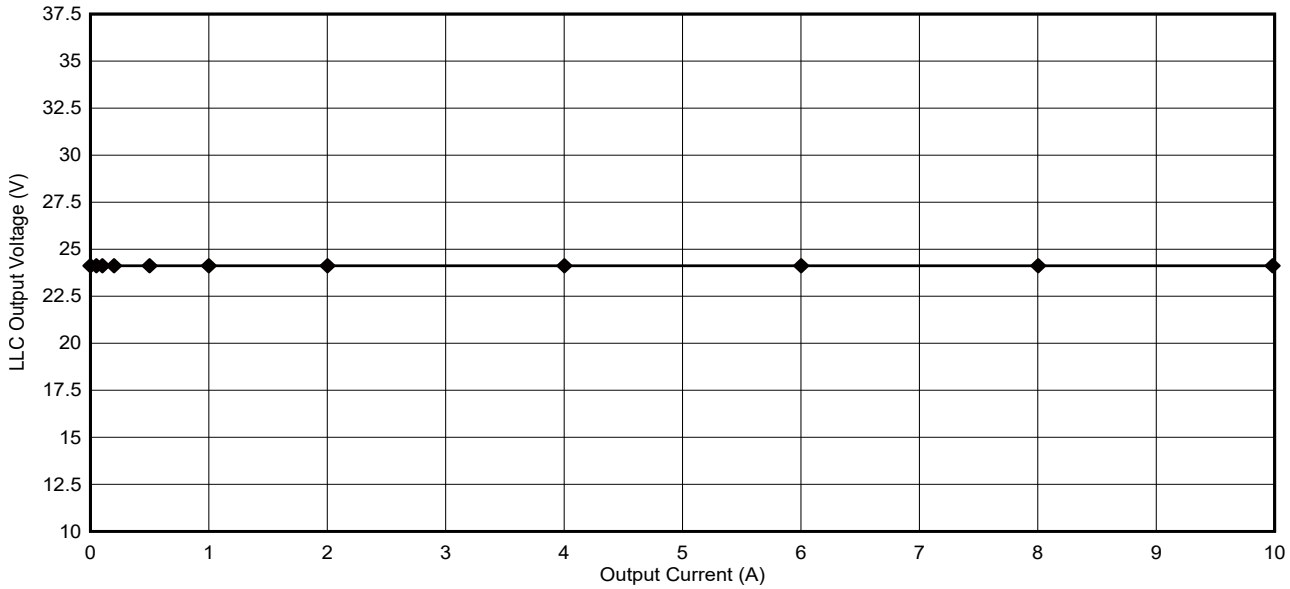


Figure 4-5. LLC Stage Static Voltage Regulation versus Load Current

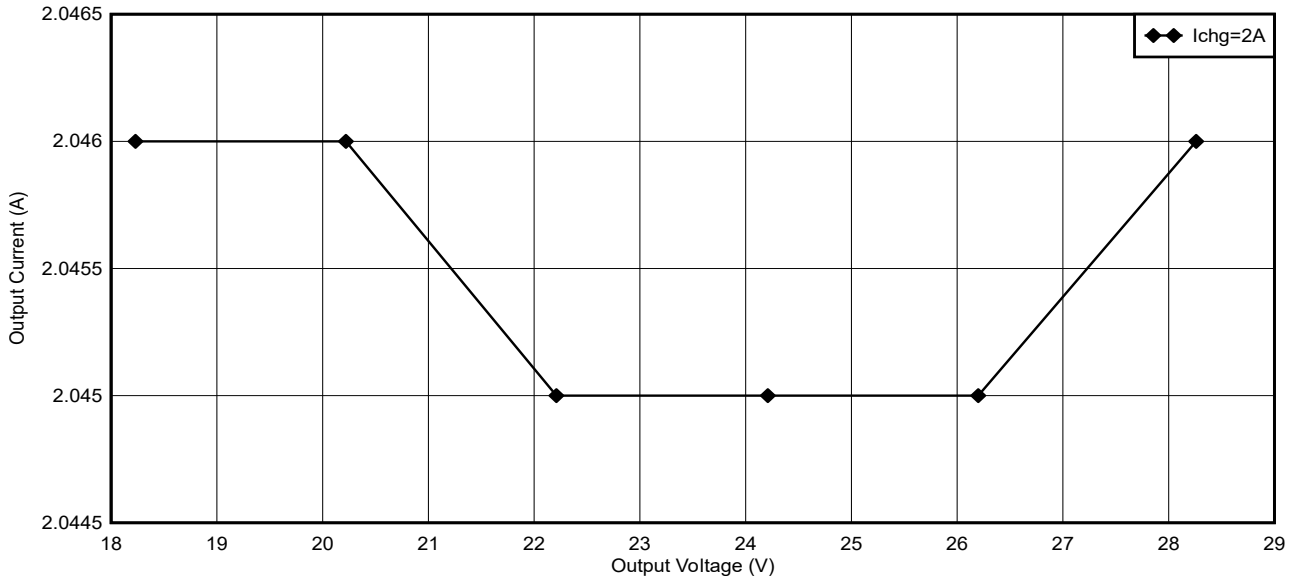


Figure 4-6. Buck-Boost Stage Current Regulation versus Battery Voltage at 2A Charging Current

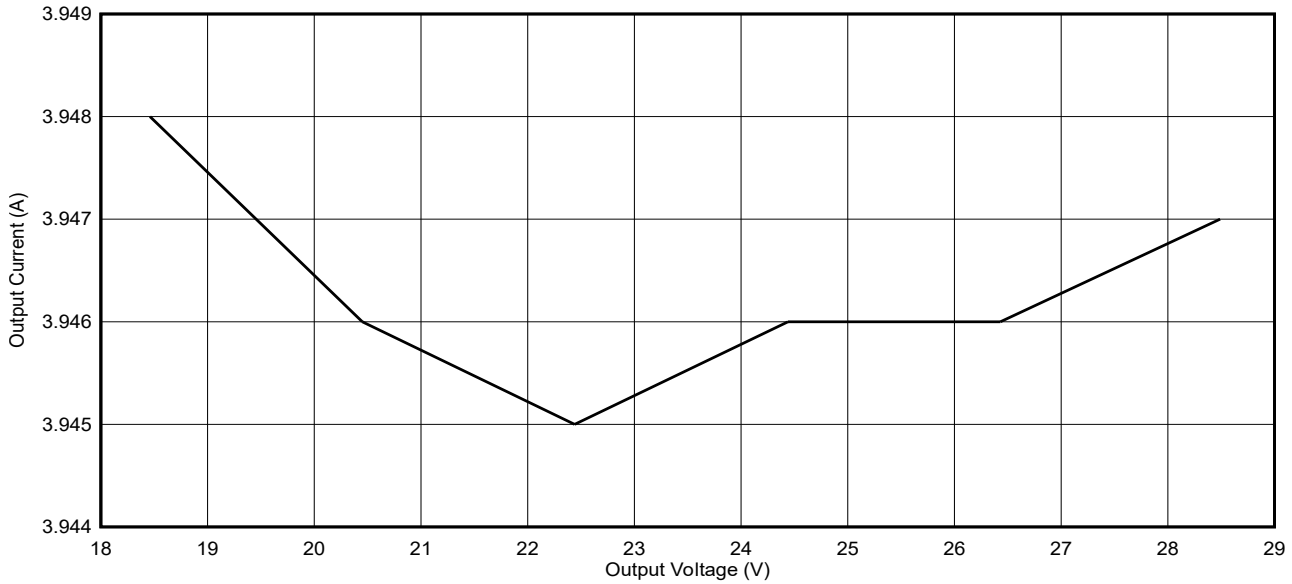


Figure 4-7. Buck-Boost Stage Current Regulation versus Battery Voltage at 4A Charging Current

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