EVALPFC-300W-ICE3PCS02/03G

300W PFC Evaluation Board with CCM PFC controller ICE3PCS02/03G

Power Management & Supply

Never stop thinking.

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EVALPFC-300W-ICE3PCS02/03G

Revision History: V1.0

Previous Version: NA

300W PFC Evaluation Board with CCM PFC controller ICE3PCS02/03G

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1 Content

The evaluation board presented here is a 300W power factor correction (PFC) circuit with 85~265VAC universal input and output of 400VDC rated voltage. The continuous conduction mode (CCM) PFC controller either ICE3PCS02G or ICE3PCS03G can be employed in this board to achieve the unity power factor.

This ICE3PCS02G and ICE3PCS03G are specially designed for applications of power supplies used in PC, server, LCD/PDP TV and Telecom, requesting high efficiency and power factor. The voltage loop compensation is integrated digitally for better dynamic response and less design effort. Appreciated for its high integrated design, ICE3PCS02G and ICE3PCS03G can achieve full requirements of the PFC application implemented in the 8-pin in DSO8 package. At the same time the number of peripheral components is minimized. The gate switching frequency is adjustable from 21kHz to 250kHz and able to synchronize with external switching frequency from 50kHz to 150kHz. In order to improve the power conversion efficiency further, the CoolMOS™ CP series and high voltage silicon carbide (SiC) schottky diode thinQ!TM are used into this boost type PFC circuit.

2 Evaluation Board

ICE3PCS01G Demoboard

3 Technical Specifications

Input voltage	85VAC~265VAC
Input frequency	47~63Hz
Output voltage and current	400VDC, 0.75A
Output power	~ 300W
Average efficiency	>95% at 115VAC
Switching Frequency	21kHz~250kHz

4 Circuit Description

Line Input

The AC line input side comprises the input fuse F1 as over-current protection. The choke L1, X2-capacitors CX1/CX2 and Y1-capacitor CY1/CY2 are used to suppress common mode noise as well as differential mode noise. RT1 is placed in series to limit inrush current during each power on.

Power Stage – Boost Type PFC Converter

After the bridge rectifier BR1, there is a boost type PFC converter consisting of L3, Q1, D1 and C2. The third generation CoolMOS™ IPP60R199P is used as the power switch Q1. BR1, Q1 and SiC Diode D1 share the same heat sink so that the system heat can be equably spread. Output capacitor C2 provides energy buffering to reduce the output voltage ripple (100Hz) to the acceptable level and meet the holdup time requirement.

PWM Control of Boost Converter

The ICE3PCS02G and ICE3PCS03G are 8-pins control IC for power factor correction converters. It is suitable for wide range line input applications from 85 to 265 VAC with overall efficiency above 93.5%. The IC supports converters in boost topology and it operates in continuous conduction mode (CCM) with average current control.

The IC operates with a cascaded control; the inner current loop and the outer voltage loop. The inner current loop of the IC controls the sinusoidal profile for the average input current. It uses the dependency of the PWM duty cycle on the line input voltage to determine the corresponding input current. This means the average input current follows the input voltage as long as the device operates in CCM. Under light load condition, depending on the choke inductance, the system may enter into discontinuous conduction mode (DCM) resulting in a higher harmonics but still meeting the Class D requirement of IEC 1000-3-2.

The outer voltage loop controls the output bulk voltage, integrated digitally within the IC. Depending on the load condition, internal PI compensation output is converted to an appropriate DC voltage which controls the amplitude of the average input current.

The IC is equipped with various protection features to ensure safe operating condition for both the system and device.

5 Circuit Operation

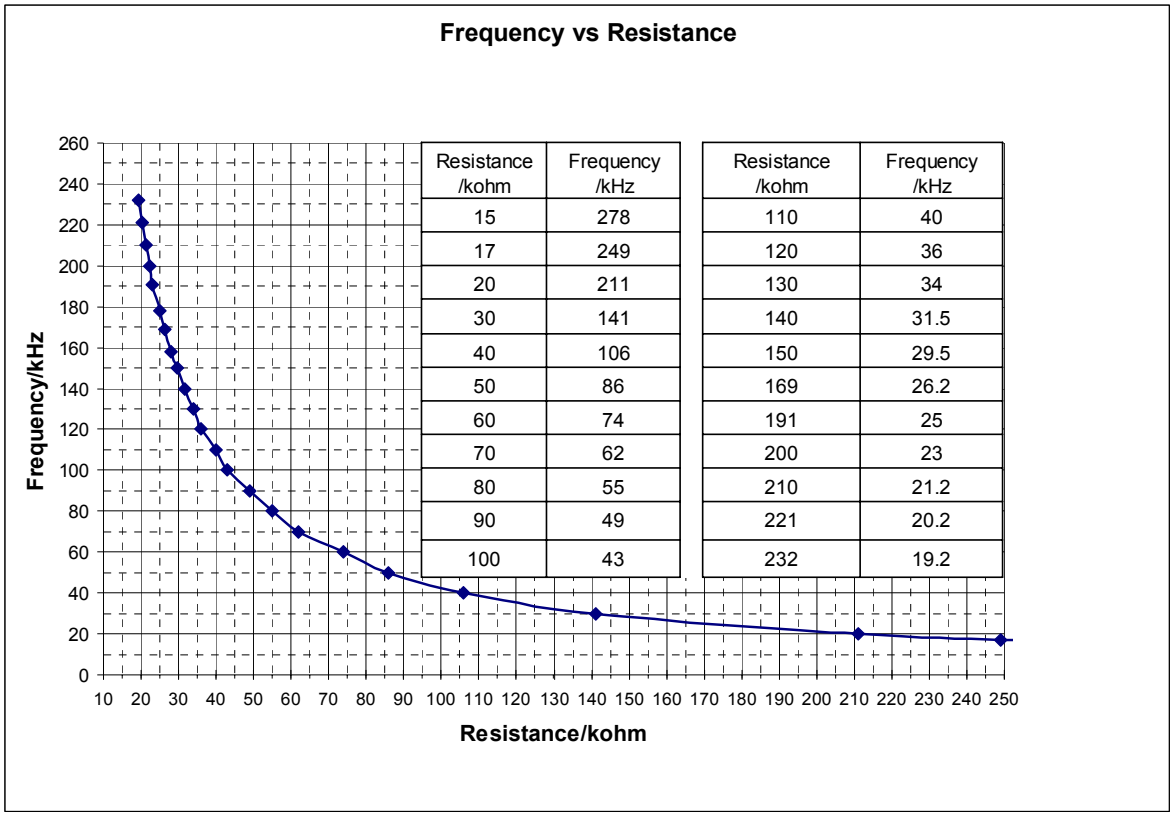
5.1 Soft Startup

During power up when the V_{OUT} is less than 95% of the rated level, internal voltage loop output increases from initial voltage under the soft-start control. This results in a controlled linear increase of the input current from 0A thus reducing the current stress in the power components.

Once V_{OUT} has reached 95% of the rated level, the soft-start control is released to achieve good regulation and dynamic response.

5.2 Gate Switching Frequency

The switching frequency of the PFC converter can be set with an external resistor R_{FREQ} at pin FREQ with reference to pin SGND. The voltage at pin FREQ is typical 1V. The corresponding capacitor for the oscillator is integrated in the device and the R_{FREQ}/frequency is given in Figure 2. The recommended operating frequency range is from 21 kHz to 250 kHz. As an example, a R_{FREQ} of 68kΩ at pin FREQ will set a switching frequency f_{SW} of 65 kHz typically.



Resistance /kohm	Frequency /kHz	Resistance /kohm	Frequency /kHz
15	278	110	40
17	249	120	36
20	211	130	34
30	141	140	31.5
40	106	150	29.5
50	86	169	26.2
60	74	191	25
70	62	200	23
80	55	210	21.2
90	49	221	20.2
100	43	232	19.2

Frequency setting

The switching frequency can be synchronized to the external pulse signal after 6 external pulses delay once the voltage at the FREQ pin is higher than 2.5V. The synchronization means two points. Firstly, the PFC switching frequency is tracking the external pulse signal frequency. Secondly, the falling edge of the PFC signal is triggered by the rising edge of the external pulse signal. The external R8 combined with R9 and the external diode, D6 can ensure FREQ pin voltage to be kept between 1.0V (clamped internally) and 5V (maximum pin voltage). If the external pulse signal has disappeared longer than 108us (typical) the switching frequency will be synchronized to internal clock set by the external resistor R8.

5.3 Protection Features

5.3.1 Input brown-out protection (BOP)

ICE3PCS03G provides a new BOP feature whereby it senses directly the input voltage for Input-Brown-Out condition via an external resistor/capacitor/diode network. This network provides a filtered value of V_{IN} which turns the IC on when the voltage at pin 5 (BOP) is more than 1.25V. The IC enters into the fault mode when BOP goes below 1.0V. The hysteresis prevents the system to oscillate between normal and fault mode. Note also that the peak of V_{IN} needs to be at least 20% of the rated V_{OUT} in order to overcome open loop protection and power up system.

5.3.2 Open loop protection (OLP)

The open loop protection is available for this IC to safe-guard the output. Whenever voltage at pin VSENSE falls below 0.5V, or equivalently V_{OUT} falls below 20% of its rated value, it indicates an open loop condition (i.e. VSENSE pin not connected). In this case, most of the blocks within the IC will be shutdown. It is implemented using a comparator with a threshold of 0.5V.

5.3.3 First over-voltage protection (OVP1)

Whenever V_{OUT} exceeds the rated value by 8%, the first over-voltage protection OVP1 is active. This is implemented by sensing the voltage at pin VSENSE with respect to a reference voltage of 2.7V. A VSENSE voltage higher than 2.7V will immediately block the gate signal. After bulk voltage falls below the rated value, gate drive resumes switching again.

5.3.4 Second over-voltage protection (OVP2)

The second OVP (OVP2) is provided in case that the first one fails due to the aging or incorrect resistors connected to the VSENSE pin. This is implemented by sensing the voltage at pin OVP with respect to a reference voltage of 2.5V. When voltage at OVP pin is higher than 2.5V, the IC will immediately turn off the gate, thereby preventing damage to bus capacitor. When the bulk voltage drops out of the hysteresis, which is below 2.3V the IC begin auto soft-start.

In normal operation the trigger level of OVP2 should be designed higher than OVP1. However in the condition of mains transient overshoot the bulk voltage may be pulled up to the peak value of mains that is higher than the threshold of OVP1 and OVP2. In this case the OVP1 and OVP2 are triggered in the same time the IC will shut down the gate drive until bulk voltage falls out of the two protection hysteresis, then resume the gate drive again. This function is available in ICE3PCS02G.

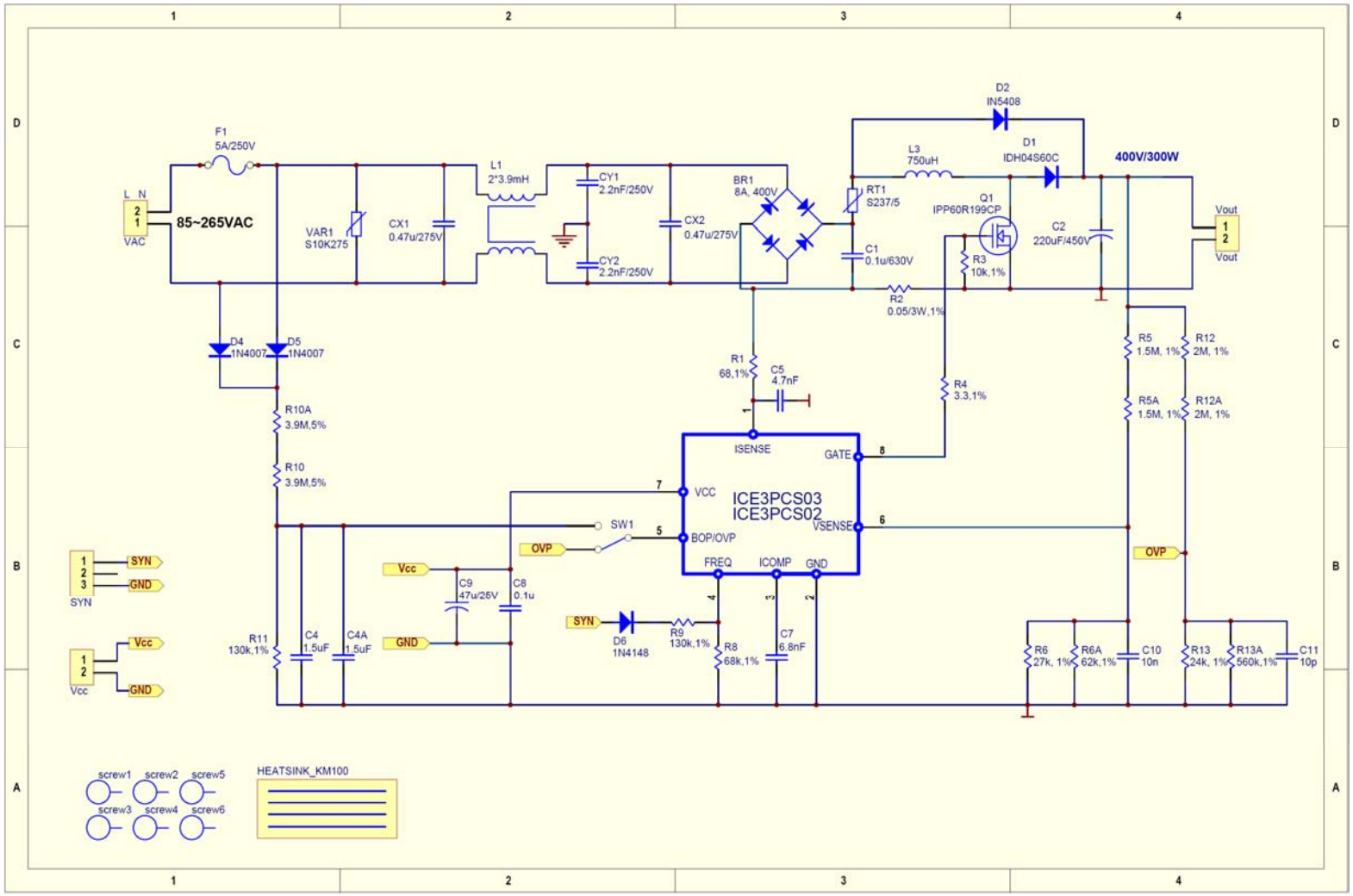
5.3.5 Peak current limit

The IC provides a cycle by cycle peak current limitation (PCL). It is active when the voltage at pin ISENSE reaches -0.4V. This voltage is amplified by a factor of -2.5 and connected to comparator with a reference voltage of 1.0V. A deglitcher with 200ns after the comparator improves noise immunity to the activation of this protection. In other words, the current sense resistor should be designed lower than -0.4V PCL for normal operation.

5.3.6 IC supply under voltage lockout

When V_{CC} voltage is below the under voltage lockout threshold V_{CCUVLO}, typical 11V, IC is off and the gate drive is internally pull low to maintain the off state. The current consumption is down to 1.4mA only.

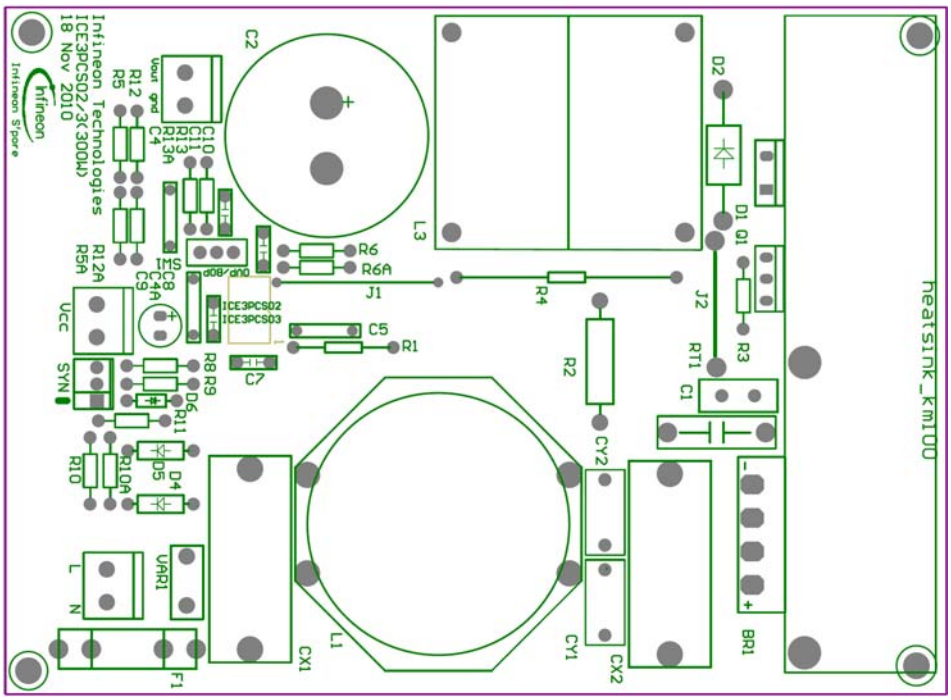
6 Circuit Diagram



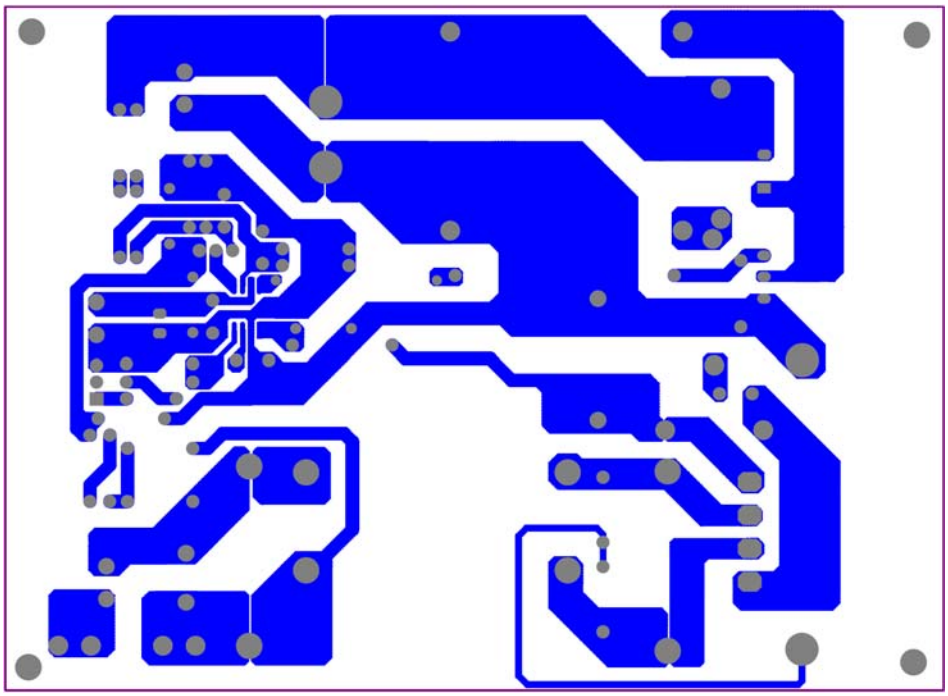
Schematic of 300W PFC demo board

7 PCB Layout

7.1 Top overlay view



7.2 Bottom layer view



8 Component List

Designator	Part Type	Description	Manufacturer/ Part No.
BR1	8A, 400V	Bridge Rectifier	Vishay / KBU8G
C1	0.1uF/630V	Ceramic Cap	Epcos / B32652A6104J
C2	220uF/450V	Electrolytic Cap	
C4	1.5 uF/50V	Ceramic Cap	
C4A	1.5 uF/50V	Ceramic Cap	
C5	4.7nF/50V	Ceramic Cap	
C7	6.8nF/50V	Ceramic Cap	
C8	0.1uF/50V	Ceramic Cap	
C9	47uF/25V	Electrolytic Cap	
C10	10nF/50V	Ceramic Cap	
C11	10pF/50V	Ceramic Cap	
CX1	0.47uF, X1, 275V	Ceramic Cap	Epcos / B32922C3474M
CX2	0.47uF, X1, 275V	Ceramic Cap	Epcos / B32922C3474M
CY1	2.2nF, Y2, 250V	Ceramic Cap	Epcos / B81123C1222M000
CY2	2.2nF, Y2, 250V	Ceramic Cap	Epcos / B81123C1222M000
(Connecter) SYNC	SIP3-MOLEX	Connector (SYNC)	
(Connecter) VCC	2-way PCB connecter	Connector (V_{CC})	
(Connecter) L N	2-way PCB connecter	Connector (V_{IN})	
(Connecter) VOUT	2-way PCB connecter	Connector (V_{OUT})	
D1	IDH04S60C	Diode	Infineon Technologies
D2	1N5408	Diode	Vishay / 1N5408
D4	1N4007	Diode	Vishay / 1N4007
D5	1N4007	Diode	Vishay /1N4007
D6	1N4148	Diode	
F1	5A	Fuse	
HEATSINK_KM100	Heatsink		
IC1	ICE3PCS02G/ ICE3PCS02G	DSO-8	Infineon Technologies
J1	jumper wire	GATE signal	
J2	jumper wire		
L1	2*3.9mH	CM Choke	Epcos / B82725J2602N20
L3	750uH	PFC Choke	
Q1	IPP60R199CP	Power MOSFET	Infineon Technologies
R1	68/0.25W, 1%	Carbon Film Resistor	
R2	0.05/3W, 1%	Metal Film Resistor	Vishay / LVR03R0500FE70
R3	10k/0.25W, 1%	Carbon Film Resistor	
R4	3.3/0.25W, 1%	Carbon Film Resistor	
R5	1.5M/0.25W, 1%	Carbon Film Resistor	
R5A	1.5M/0.25W, 1%	Carbon Film Resistor	
R6	27k/0.25W, 1%	Carbon Film Resistor	
R6A	62k/0.25W, 1%	Carbon Film Resistor	
R8	68k/0.25W, 1%	Carbon Film Resistor	
R9	130k/0.25W, 1%	Carbon Film Resistor	
R10	3.9M/0.25W, 5%	Carbon Film Resistor	
R10A	3.9M/0.25W, 5%	Carbon Film Resistor	

R11	130k/0.25W, 1%	Carbon Film Resistor	
R12	2M/0.25W, 1%	Carbon Film Resistor	
R12A	2M/0.25W, 1%	Carbon Film Resistor	
R13	24k/0.25W, 1%	Carbon Film Resistor	
R13A	560k/0.25W, 1%	Carbon Film Resistor	
RT1	S237/5	NTC Thermistor	Epcos / B57237S509M
SCREW1	Diameter:2mm	PCB stand	
SCREW2	Diameter:2mm	PCB stand	
SCREW3	Diameter:2mm	PCB stand	
SCREW4	Diameter:2mm	PCB stand	
SCREW5	Diameter:2mm	Heatsink	
SCREW6	Diameter:2mm	Heatsink	
SW1	3 pin PCB header		
VAR1	S10K275	Varistor	Epcos / B72210S271K101

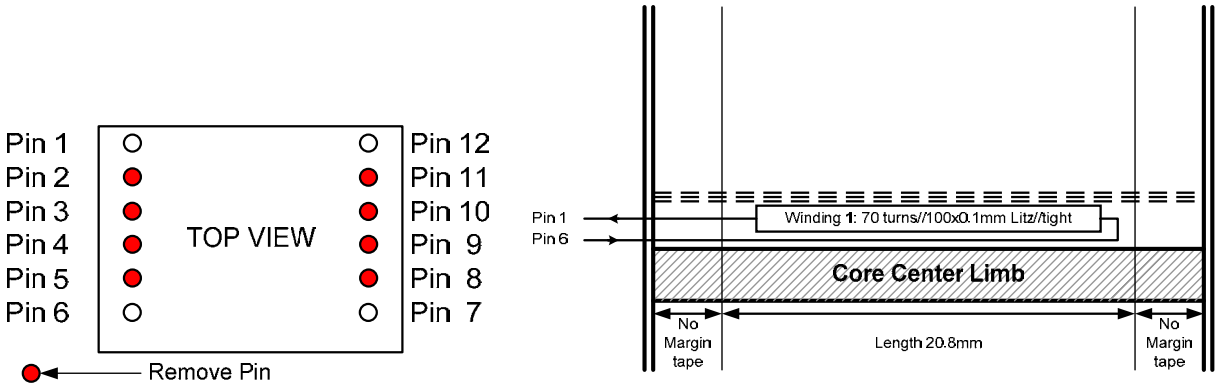
9 Boost Choke Layout

Core: PQ-core PQ3535 (TDK)

Material: PC95

Inductance: L=750uH

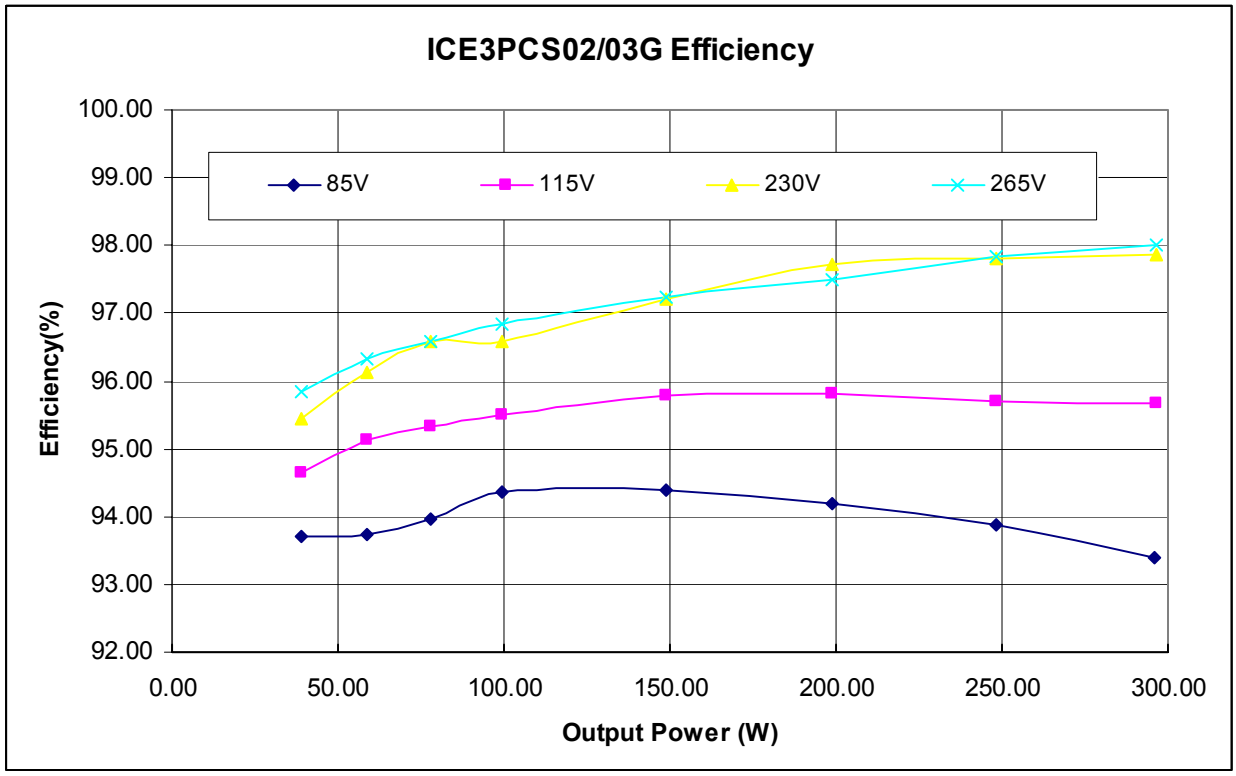
Windings	*Start*	*End*	*Wire*	*Turns*	*Layers*	*Method*
1	**1**	**6**	100x0.1mm Litz	70	4 or 5	Tight



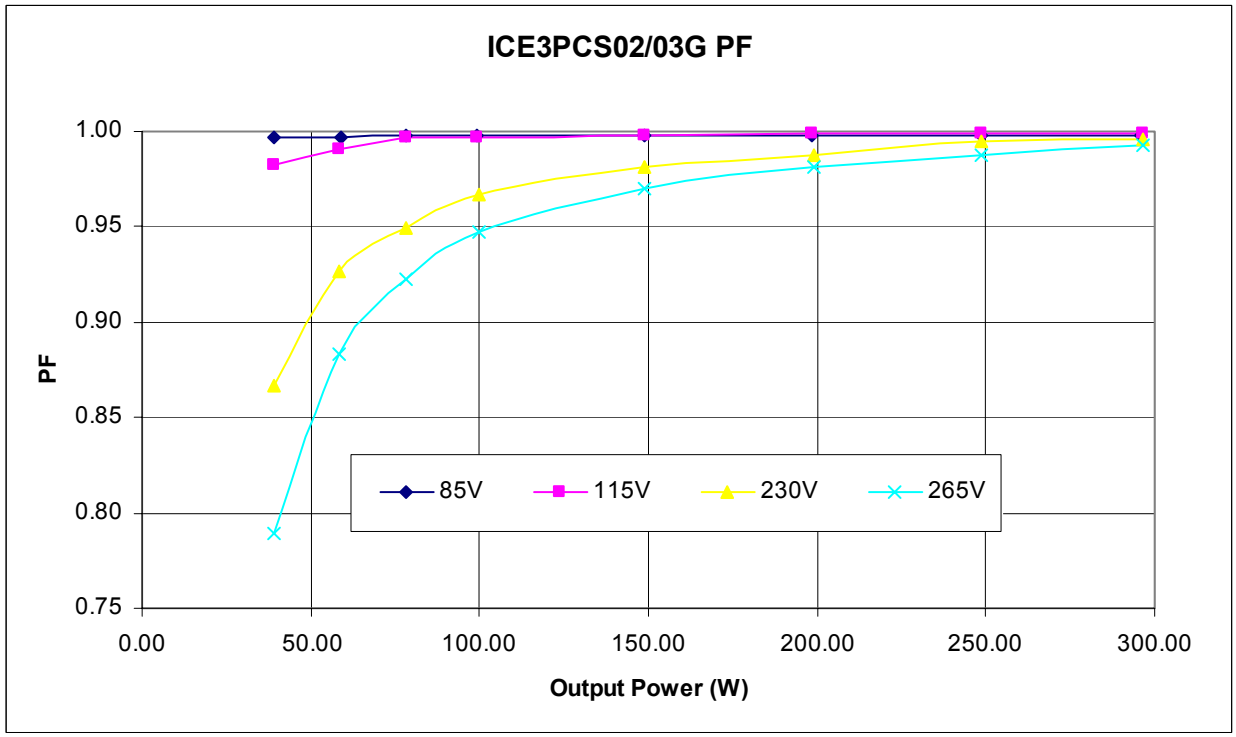
10 Test report

10.1 Load and Line Test

Input	V_{in}(V)	I_{in}(I)	V_{out}(V)	I_{out}(I)	P_{out}(W)	Efficiency	PF
85V	84.79	0.49	399.90	0.10	38.99	93.72	1.00
	84.67	0.74	399.90	0.15	58.71	93.72	1.00
	84.56	0.98	399.80	0.20	78.02	93.97	1.00
	84.44	1.25	399.80	0.25	99.46	94.35	1.00
	84.15	1.88	399.80	0.37	149.04	94.39	1.00
	83.86	2.52	399.70	0.50	198.72	94.18	1.00
	83.56	3.17	399.70	0.62	248.49	93.87	1.00
	83.28	3.81	399.70	0.74	296.18	93.41	1.00
115V	114.77	0.37	399.90	0.10	39.19	94.65	0.98
	114.69	0.54	399.90	0.15	58.63	95.14	0.99
	114.61	0.72	399.80	0.20	78.04	95.34	1.00
	114.52	0.91	399.80	0.25	99.49	95.51	1.00
	114.31	1.36	399.80	0.37	149.05	95.79	1.00
	114.10	1.82	399.70	0.50	198.73	95.83	1.00
	113.90	2.28	399.70	0.62	248.49	95.71	1.00
	113.70	2.73	399.70	0.74	296.28	95.66	1.00
230V	229.81	0.21	399.90	0.10	39.20	95.44	0.87
	229.77	0.29	399.90	0.15	58.64	96.14	0.93
	229.73	0.37	399.80	0.20	78.12	96.60	0.95
	229.68	0.46	399.80	0.25	99.53	96.58	0.97
	229.59	0.68	399.80	0.37	149.08	97.21	0.98
	229.48	0.90	399.70	0.50	198.74	97.73	0.99
	229.38	1.11	399.70	0.62	248.49	97.81	0.99
	229.29	1.33	399.70	0.74	296.30	97.86	1.00
265V	264.84	0.20	399.90	0.10	39.21	95.85	0.79
	264.81	0.26	399.90	0.15	58.65	96.32	0.88
	264.77	0.33	399.80	0.20	78.07	96.57	0.92
	264.73	0.41	399.80	0.25	99.55	96.84	0.95
	264.65	0.60	399.80	0.37	149.10	97.25	0.97
	264.56	0.79	399.70	0.50	198.80	97.50	0.98
	264.47	0.97	399.70	0.62	248.49	97.84	0.99
	264.39	1.15	399.70	0.74	296.26	98.01	0.99



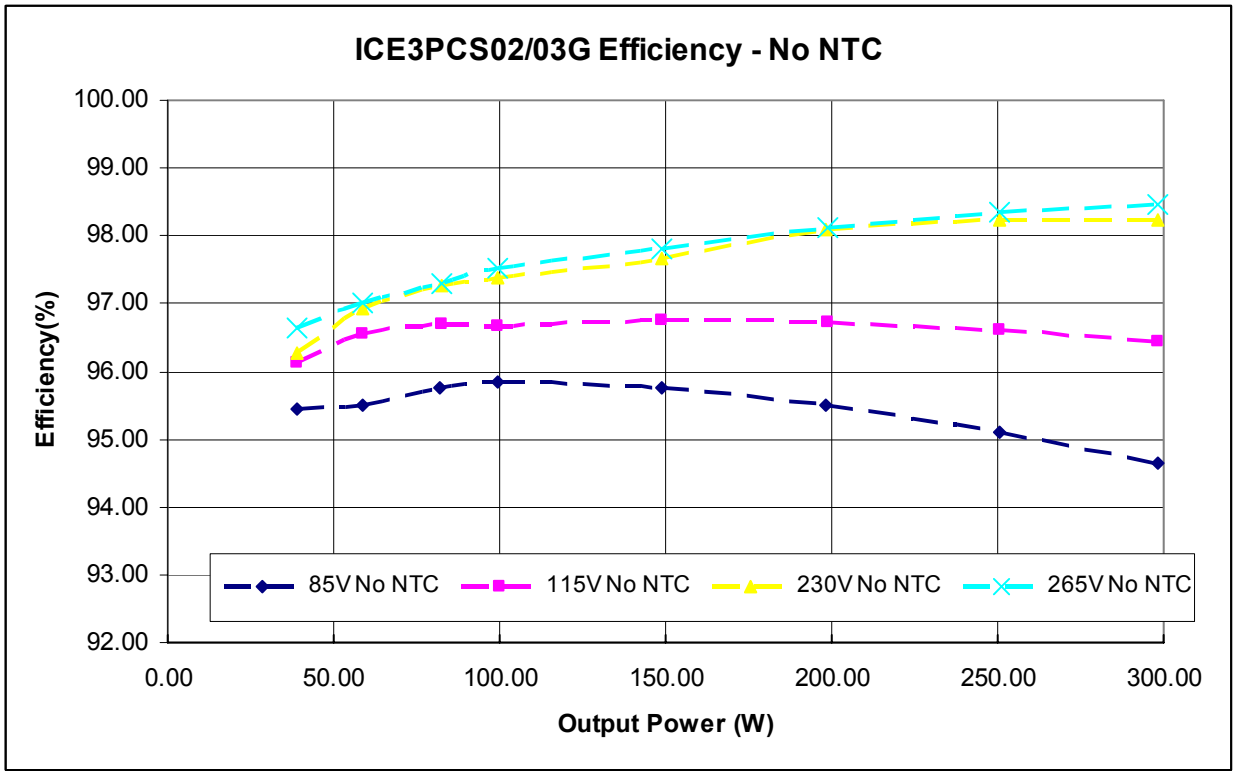
PFC stage efficiency



Power factor

10.2 Load and Line Test without NTC(5Ω)

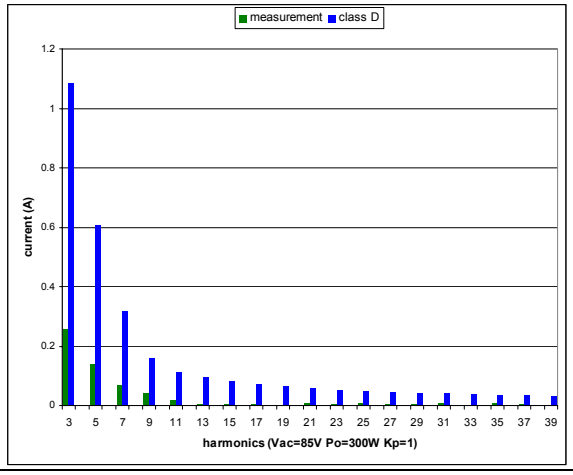
Input	V_{in}(V)	I_{in}(I)	V_{out}(V)	I_{out}(I)	P_{out}(W)	Eff.	PF
85V	84.78	0.48	399.90	0.10	38.79	95.44	1.00
	84.67	0.73	399.90	0.15	58.59	95.49	1.00
	84.53	1.02	399.90	0.21	82.26	95.76	1.00
	84.43	1.23	399.90	0.25	99.40	95.84	1.00
	84.14	1.85	399.90	0.37	148.97	95.77	1.00
	83.84	2.48	399.90	0.50	198.55	95.51	1.00
	83.51	3.16	399.90	0.63	250.37	95.10	1.00
	83.22	3.79	399.90	0.75	298.09	94.65	1.00
115V	114.77	0.36	399.90	0.10	39.20	96.14	0.98
	114.68	0.53	399.90	0.15	58.61	96.56	0.99
	114.58	0.74	399.90	0.21	82.28	96.69	1.00
	114.51	0.90	399.90	0.25	99.43	96.67	1.00
	114.30	1.35	399.90	0.37	149.03	96.77	1.00
	114.09	1.80	399.90	0.50	198.58	96.73	1.00
	113.85	2.28	399.90	0.63	250.41	96.60	1.00
	113.64	2.72	399.90	0.75	298.07	96.43	1.00
230V	229.81	0.21	399.90	0.10	39.20	96.28	0.86
	229.76	0.28	399.90	0.15	58.62	96.92	0.92
	229.72	0.39	399.90	0.21	82.31	97.28	0.95
	229.68	0.46	399.90	0.25	99.57	97.37	0.97
	229.58	0.68	399.90	0.37	149.08	97.68	0.98
	229.48	0.89	399.90	0.50	198.35	98.10	0.99
	229.36	1.12	399.90	0.63	250.37	98.24	0.99
	229.24	1.33	399.90	0.75	298.09	98.24	1.00
265V	264.84	0.20	399.90	0.10	39.20	96.64	0.78
	264.80	0.26	399.90	0.15	58.61	97.02	0.88
	264.76	0.34	399.90	0.21	82.31	97.31	0.93
	264.73	0.41	399.90	0.25	99.58	97.54	0.95
	264.64	0.59	399.90	0.37	149.11	97.80	0.97
	264.55	0.78	399.90	0.50	198.73	98.11	0.98
	264.45	0.98	399.90	0.63	250.45	98.35	0.99
	264.35	1.15	399.90	0.75	298.05	98.47	0.99



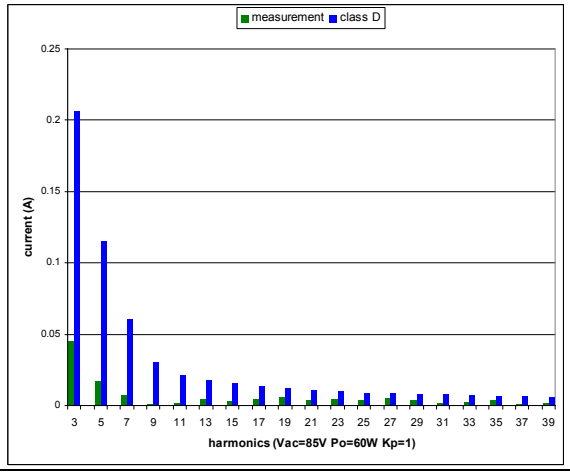
PFC stage efficiency without NTC (5Ω)

Harmonic test according to EN61000-3-2 Class D requirement

Test condition I: 85VAC input

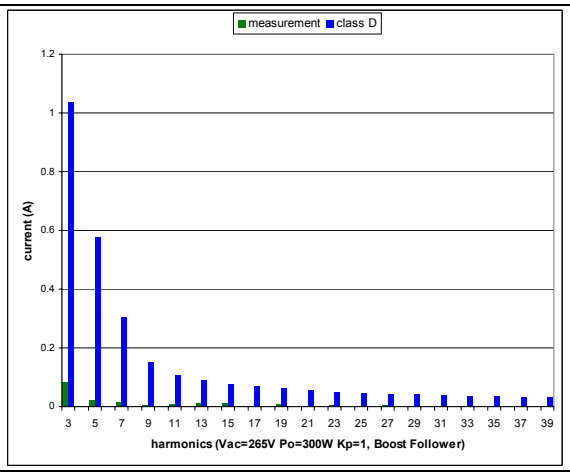


Harmonics at 300W output

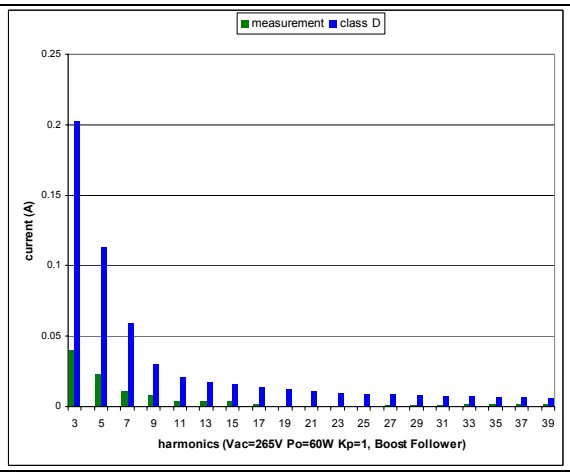


Harmonics at 60W output

Test condition II: 265VAC input

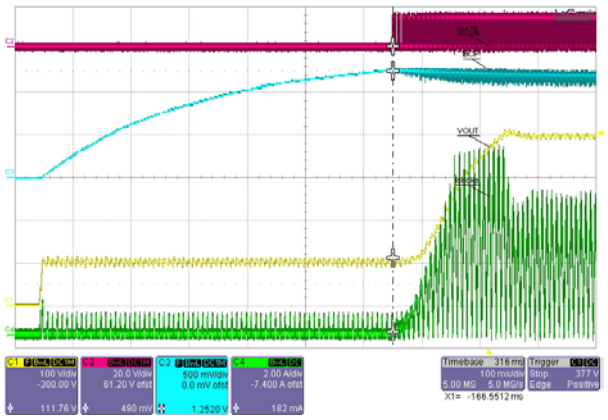
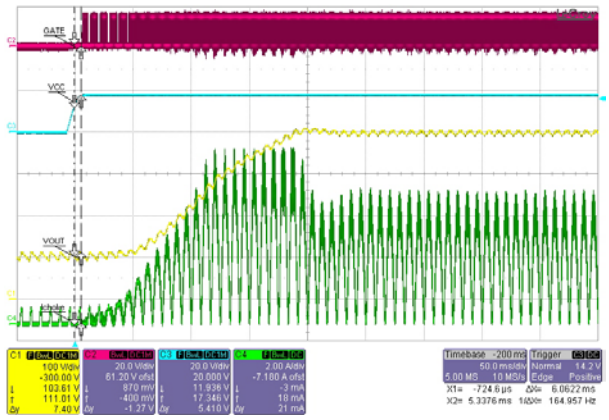


Harmonics at 300W output



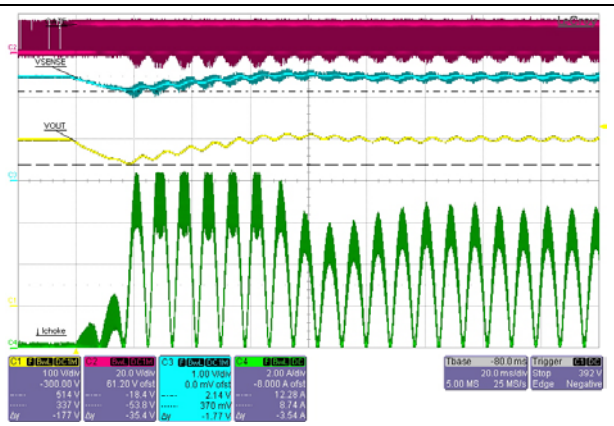
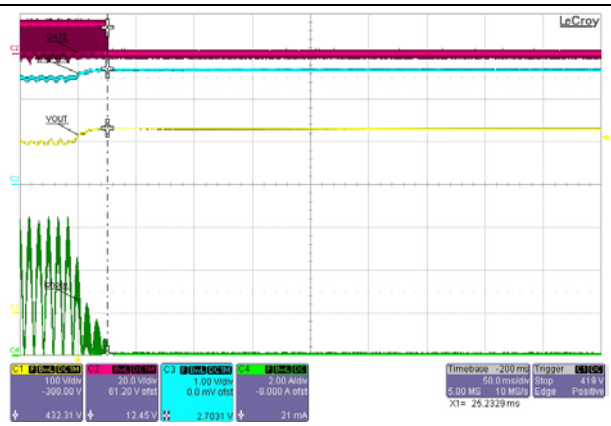
Harmonics at 60W output

11 Test Waveforms

	
BOP triggered startup	VCC triggered startup

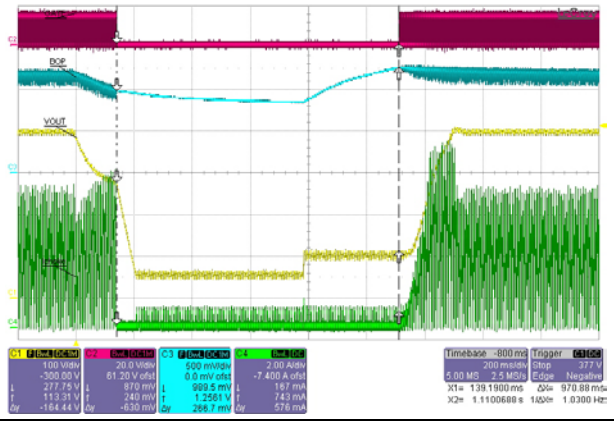
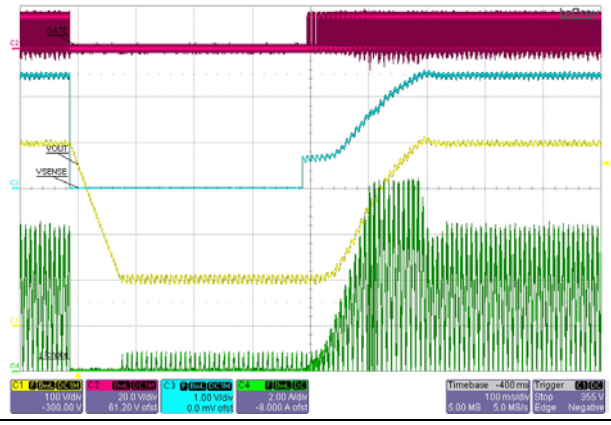
Startup test at 85VAC, 300W

During startup the average current of PFC choke increases from zero to maximum limited by PCL and PFC output voltage rises gradually with very slight overshoot.

	
Pout from 0W to 300W	Pout from 300W to 0W

Load jump test at 85VAC

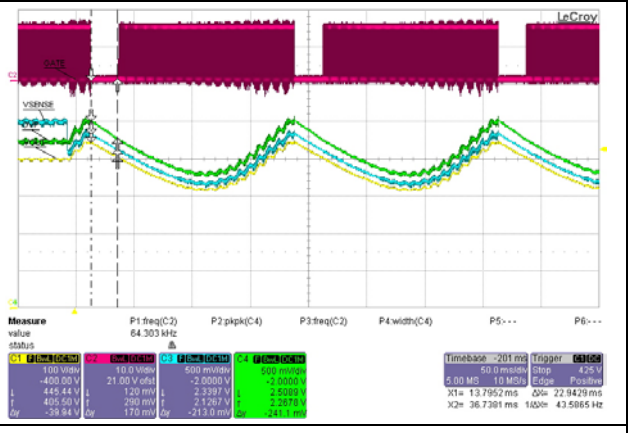
The under shoot of output voltage is only 63V when load jump from no load to full load at 85Vac while the overshoot is within 33V vice versa. The choke current shows no distortion during load dynamic change.

	
Enter brown-out and leave brown-out , Pout: 300W	Open Loop protection at 85V, Pout: 150W

Brownout and OLP test

The gate drive is latched off once BOP pin voltage is lower than 1V and initiates another soft-startup once BOP voltage is higher than 1.25V as shown in the left picture.

The gate drive can also be latched off once Vsense pin voltage is below 0.5V indicating an inadequate output voltage and initiates another soft-startup once Vsense voltage is higher than 0.5V as shown in the right picture.



Auto Restart Mode

OVP2 test

When OVP2 happens the gate drive the will shut down and enter auto startup when the voltage at OVP pin drop below 2.3V.

12 References:

[1] ICE3PCS02G and ICE3PCS03G datasheet, Infineon Technologies AG, 2010.

[2] Luo Junyang, Liu Jianwei and Jeoh Meng Kiat, “Design tips for CCM PFC controller ICE2PCSxx”, Application note, Infineon Technologies, 2008.

[3] Lim Teik Eng, Li Dong and Liu Jian Wei, “300W PFC evaluation board with CCM PFC controller ICE3PCS01G”, Application note, Infineon Technologies, 2010.

[4] Luo Junyang, Liu Jianwei and Jeoh Meng Kiat, “ICE1PCS01 based boost type CCM PFC design guide – control loop modeling”, Application note, Infineon Technologies, 2007.