AN-EVAL-1HS01G-1-200W

200 W 24 V 6 A & 12 V 5 A SMPS demonstrator with ICE1HS01G-1

Application Note

About this document

Scope and purpose

This document is a 200 W 24 V 6 A & 12 V 5 A 280 V_{AC} input off-line half bridge LLC resonant converter demonstrator board using Infineon ICE1HS01G-1.

Intended audience

This document is intended for users of the ICE1HS01G-1 who wish to design a system of high efficiency, simple in design, low cost and high reliable in half bridge (HB) LLC resonant converter for application of LED/OLED/LCD/PDP TV, AC-DC adapter and audio SMPS.

Table of Contents

1 Abstract

The demo board described in this paper is a 200W half bridge LLC resonant converter using LLC controller ICE1HS01G-1, which is an 8-pin LLC controller developed by Infineon Technologies. ICE1HS01G-1 is specially designed for applications of switch mode power supplies used in LED / OLED / LCD / PDP TV, AC/DC adapter and Audio system.

ICE1HS01G-1 is an 8-pin DSO-8 controller IC, the PCB layout can be easily implemented. Moreover, it includes all necessary control strategies for HB LLC resonant converter. ICE1HS01G-1 allows the designer to choose suitable operation frequency range by programming the oscillator with an external resistor. And the built-in soft-start function to limit both the inrush current and the overshoot of output voltage is also provided. In addition, ICE1HS01G-1 performs all necessary protection functions in HB LLC resonant converters. All of these make ICE1HS01G-1 an outstanding product for HB LLC resonant converter in the market.

2 Demonstrator board

The 200W half bridge LLC resonant converter demo board with ICE1HS01G-1 is implemented as shown in Figure 1. The LLC stage's full load efficiency reaches >93.9%.

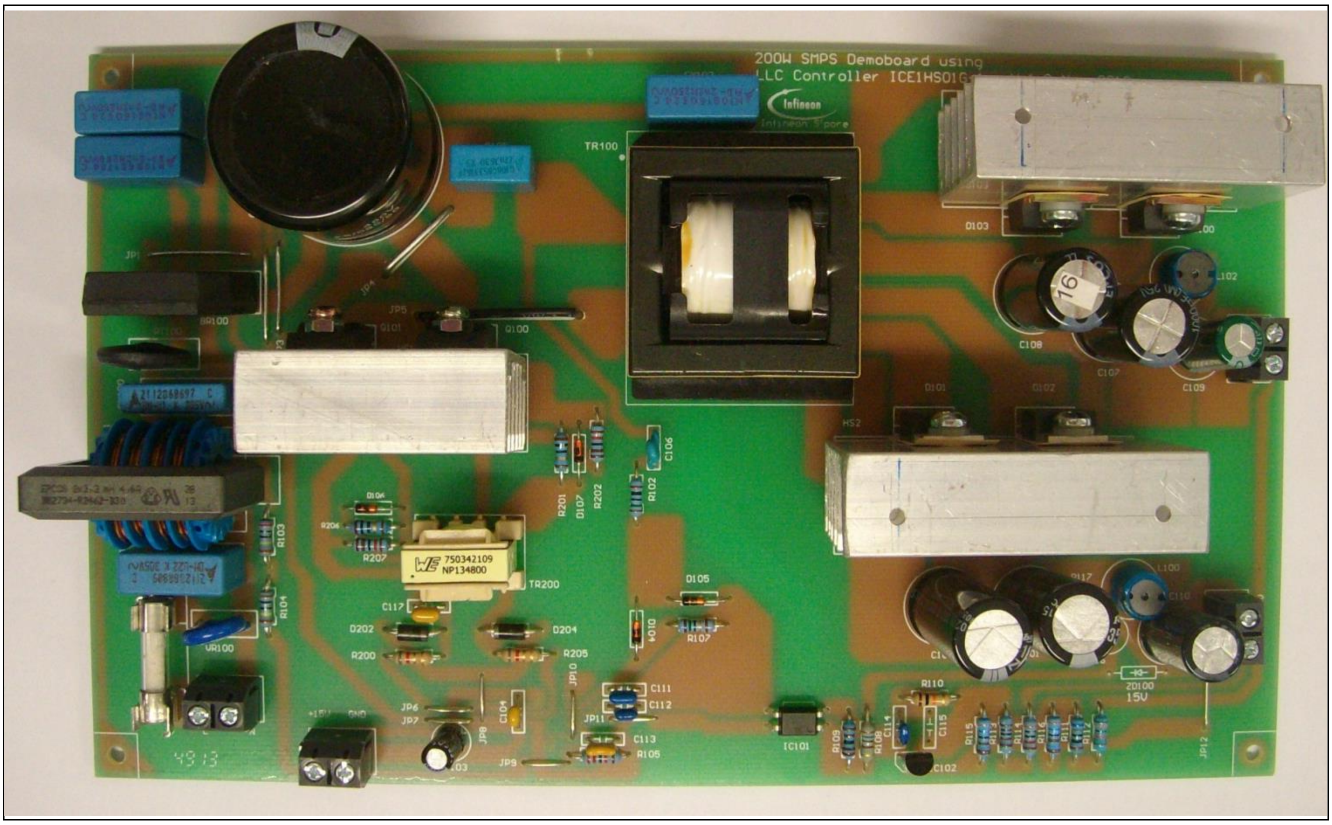

Figure 1 EVAL-1HS01G-1-200W half bridge LLC resonant converter (top view)

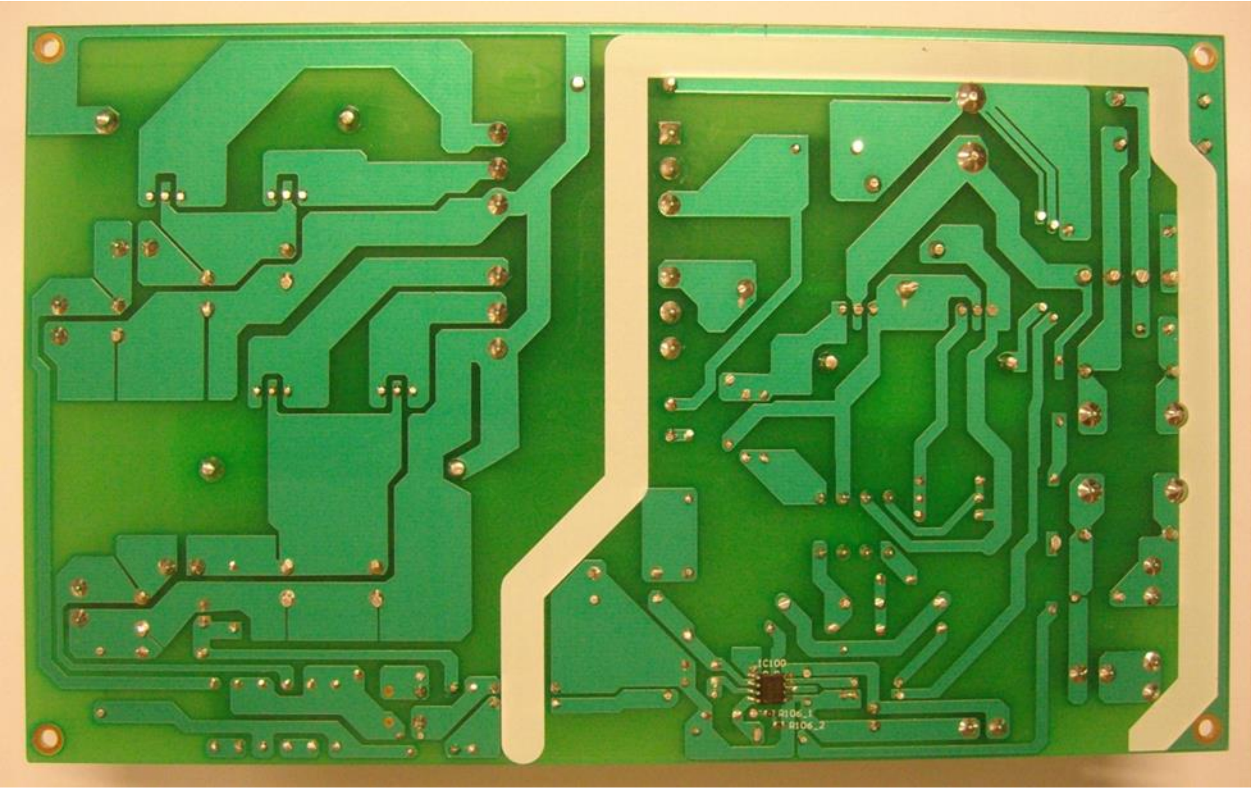

Figure 2 EVAL-1HS01G-1-200W half bridge LLC resonant converter (bottom view)

3 Specifications of demonstrator board

Table 1 Specifications of EVAL-1HS01G-1-200W

Nominal AC Input voltage	280 V_{AC}
Nominal DC Input voltage	380 V_{DC}
Mains under voltage protection point	285 V_{DC}
Auxiliary power supply for IC V_{CC}	15 V_{DC}
Nominal output full load	24 V 6 A, 12 V 5 A
Switching frequency	95kHz @ 24 V 6 A,12 V 5 A and 380 V_{DC} input
Form factor case size (L x W x H)	200mm x 120mm x 32mm

4 Features of ICE1HS01G-1

Table 2 Features of ICE1HS01G-1

Maximum 600kHz switching frequency
Adjustable minimum switching frequency with high accuracy
50% duty cycle
Mains input under voltage protection with adjustable hysteresis
Two levels of over-current protection: frequency shift and latch off
Open-loop/over load protection with extended blanking time
Built-in digital and nonlinear soft start
Adjustable restart time during fault protection period

5 Circuit description

In actual application, the LLC stage is used to follow a PFC pre-regulator. In this demo board, in order to simplify and speed up the LLC controller's feature evaluation, the conventional bridge rectifier BR100, instead of PFC, is used to provide high input DC voltage for the downstream LLC stage. Thus, around 280 V_{AC} input voltage is recommended to feed this demo board, and accordingly 380 V_{DC} voltage across bulk capacitor C100 can be achieved.

The AC line input side comprises the input fuse FUSE100 as over-current protection. The X2 Capacitors CX100, CX101 and Choke L101 and Y1 capacitors CY100 and CY101 forms a main filter to minimize the feedback of RFI into the main supply. NTC resistor RT100 is placed in series with input to limit the initial peak inrush current. After the bridge rectifier BR100, together with a smoothing capacitor C100, a voltage of 300 V_{DC} to 400 V_{DC} is provided, depending on mains input voltage, to simulate the real operation condition with front end PFC pre-regulator.

Also, the bulk capacitor C100 can be directly connected to an external DC power supply, thus the 380 V_{DC} can be obtained. This measure makes sense when the customers want to evaluate the LLC stage's efficiency.

The second stage is a half bridge LLC resonant converter, operating in zero voltage switching mode. The controller ICE1HS01G-1 is an 8 pin LLC controller, which incorporates the necessary functions to drive the half bridge's high side and low side MOSFETs (Q100 and Q101) by a 50% duty cycle with dead time. The switching frequency can be changed by ICE1HS01G-1 to regulate the output voltage against the load and input voltage variations. During operation, the primary MOSFETs Q100 and Q101 are turned-on under ZVS condition and the secondary rectifier diodes D100~D103 are turned-on and turned-off under ZCS condition. Hence high power conversion efficiency can be achieved.

The Driver Circuit can be implemented by cost-effective pulse transformer. As shown in Figure-7, Pulse transformer TR200 is used to transmit the driver signal to MOSFETs for isolation purpose.

The mains transformer TR100 uses the magnetic integration approach, incorporating the resonant series and shunt inductances. Thus, no additional external coils are needed for the resonance. The transformer configuration chosen for the secondary winding is center-tapped, and the output rectifiers D100~D103 are schottky diodes, in order to limit the power dissipation.

In case of a short circuit, the current flowing through the primary winding is detected by the lossless circuit (C106, C111, D104, D105, R102, and R107) and the resulting signal is fed into CS Pin.

In case of overload, the voltage on CS pin will overpass an internal threshold 0.8V that triggers a protection mode which keeping the current flowing in the circuit at a safe level. In addition, the blanking time and the restart time can be adjusted by external components.

6 Circuit Operation

6.1 Startup Operation

The controller ICE1HS01G-1 is targeting at applications with auxiliary power supply. In most cases, a front-end PFC pre-regulator with a PFC controller is used in the same system.

After IC supply voltage is higher than 12V, and if the voltage on VINS pin is higher than 1.25V, IC will start switching with soft start. The soft start function is built inside the IC with a digital manner. During soft start, the switching frequency of the MOSFET is controlled internally by changing the current I_{SS} instead of by the feedback voltage. The charging current I_{SS} during soft start, which determines the switching frequency, is reduced step by step as shown in product datasheet [1]. The maximum duration of soft start is 32ms with 1ms for each step. Figure 3 illustrates the actual switching frequency vs start time when R_{FMIN}=25kΩ. During soft start, the frequency starts from 209 kHz, and step by step drops to normal operation point.

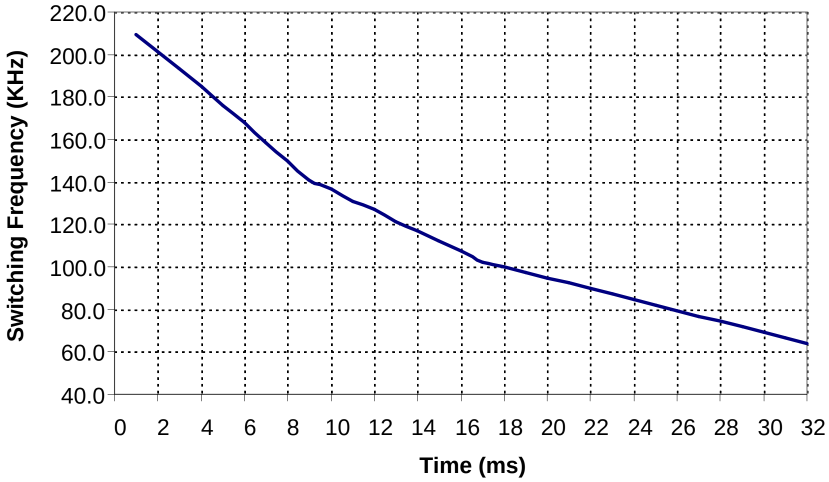

Figure 3 Switching frequency during soft start @ R_{Fmin}=25kΩ

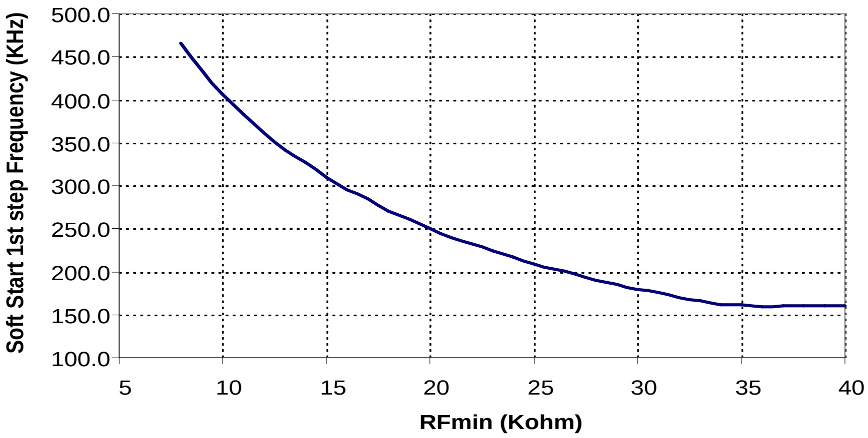

Figure 4 Soft start 1st step switching frequency vs R_{Fmin}

The soft start 1st step switching frequency, maximum frequency during soft start, is also closely related to the minimum switching frequency fixed by external RFmin resistance. Figure 4 illustrates the relationship between the 1st step frequency and R_{Fmin}.

During soft start, the overload protection is disabled because FB voltage is high.

6.2 Output Voltage Regulation

The minimum switching frequency is a very important factor to guarantee the LLC topology output voltage regulation at low line input and full load condition. ICE1HS01G-1 allows the minimum switching frequency easily programmed by connecting an external resistor R_{FMIN} between FMIN pin and ground.

The FMIN pin provides a precise 1.5V reference. The resistor R_{FMIN}, connected from FMIN pin to GND, determines the current (I_{FMIN}) flowing out of FMIN pin. Around one-tenth of I_{FMIN} is defined as the minimum charging current (I_{chg_min}), which in turn defines the minimum switching frequency. The maximum switching frequency during normal operation and the switching frequency variation range during soft start and over current protection are all related to this current flowing out of FMIN pin, which is discussed in the product datasheet [1].

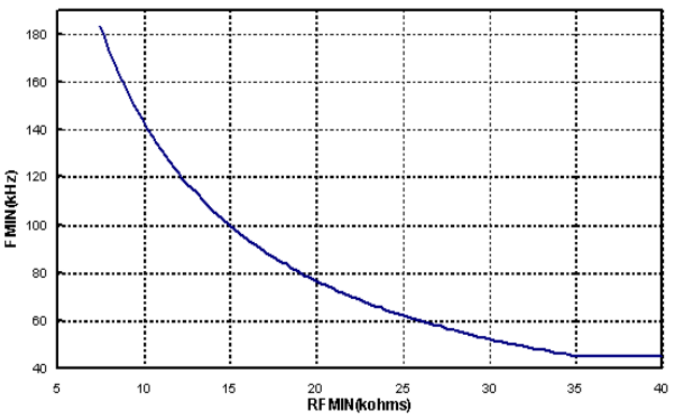

Figure 5 Minimum switching frequency VS R_{FMIN}

The output load information is fed into the controller through feedback voltage V_{FB}. Inside the IC, the feedback (FB) pin is connected to the 5V voltage source through a pull-up resistor R_{FB}. Outside the IC, this pin is connected to the collector of opto-coupler. Normally, a ceramic capacitor C_{FB} can be put between this pin and ground for signal smoothing purpose, also C_{FB} is used to determine the extended blanking time for over load protection, which will be discussed in section 7.3.

If the output load is increased, and consequently V_{FB} is higher, ICE1HS01G-1 will reduce the switching frequency to regulate the output voltage and vice versa. The regulation of switching frequency is achieved by changing the charging current I_{FB}. The relationship between I_{FB} and V_{FB} can be found in product datasheet [1]. The effective range of feedback voltage V_{FB} is from 1V to 4V. Figure 6 graphs the relationship between the actual switching frequency and feedback voltage V_{FB} when R_{FMIN}=25kΩ.

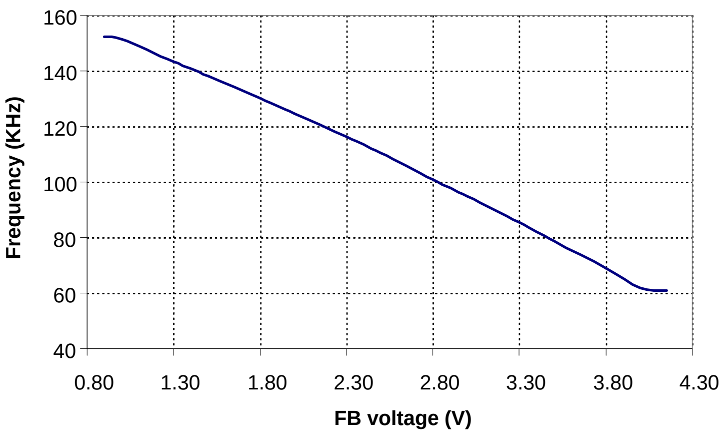

Figure 6 Switching frequency VS feedback @ R_{Fmin}=25kΩ

7 Protection Features

7.1 V_{CC} Under Voltage Protection

The controller ICE1HS01G-1 is targeting at applications with auxiliary power supply. In most cases, a front-end PFC pre-regulator with a PFC controller is used in the same system.

The controller starts to operate when the supply voltage V_{CC} reaches the on-threshold, typically 12V. The minimum operating voltage after turn-on, V_{VCCoff}, is typically 11V. The maximum supply voltage V_{VCCmax} is 18V. It is suggested that IC is supplied with a regulated dc power supply for stable operation. At the same time, a small bypass filter capacitor is suggested to be put between V_{CC} and GND pins, as closely as possible.

7.2 Over Current Protection

Current sense pin in ICE1HS01G-1 is only for protection purpose. ICE1HS01G-1 features two-level over current protection. In case of over-load condition, the lower OCP level, 0.8V, will be triggered, the switching frequency will be increased according to the duration and power of the over load. The higher OCP level, 1.6V, is used to protect the converter if transformer winding is shorted. When V_{CS} reaches 1.6V, the IC will be latched immediately.

If V_{CS} is higher than 0.8V, IC will boost up the switching frequency. If V_{CS} is lower than 0.75V, IC will resume to normal operation gradually. If V_{CS} is always higher than 0.8V for 1.5ms, the frequency will rise to its maximum level and vice versa.

To sum up, ICE1HS01G-1 will increase the switching frequency to limit the resonant current in case of temporary over-load and will also decrease the switching frequency to its normal value after over-load condition goes away.

7.3 Over Load Protection

In case of output over load or open control loop fault, the FB voltage will increase to its maximum level. If FB voltage is higher than V_{FBH} and this condition last longer than a fixed blanking time of T_{OLP} (20ms), the IC will start the extended blanking timer. The extended blanking timer is realized by charging and discharging the filter capacitor C_{FB} via the internal pull up resistor R_{FB} and switch Q_{FB}. Accordingly the voltage across C_{FB} varies between V_{FBL} and V_{FBH}.

The time needed for C_{FB} being charged from V_{FBL} to V_{FBH} can be calculated as:

$$t_{chg\_olp} = -\ln\left(\frac{V_{dd} - V_{FBH}}{V_{dd} - V_{FBL}}\right) \cdot R_{FB} \cdot C_{FB}$$

The time needed for C_{FB} being discharged from V_{FBH} to V_{FBL} can be calculated as:

$$t_{dischg\_olp} = \ln\left(\frac{V_{FBH}}{V_{FBL}}\right) \cdot R_{QFB} \cdot C_{FB}$$

Thanks to an internal counter, the total extended blanking time can be calculated as:

$$t_{ext\_blank} = 512 \cdot (t_{chg\_olp} + t_{dischg\_olp})$$

where R_{QFB} is switch Q_{FB}'s on resistance, R_{QFB}=900ohm, V_{FBH} =4.5V, V_{FBL} =0.5V.

For example, if C_{FB} is 680pF, t_{chg_olp} is about 30us, t_{dischg_olp} is about 1.4us, t_{ext_blank} is about 16ms.

If the converter returns to normal operation during the extended blanking time, IC will reset all faults timer to zero and return to normal operation.

After IC enters into OLP, both switches will be stopped. However, the IC remains active and will try to start with soft start after an adjustable period. This period is realized by charging and discharging the capacitor C_{INS}, connected to VINS pin, for N_{OLP_R} times (N_{OLP_R}=2048), accordingly the voltage across C_{INS} varies between V_{INSH} and V_{INSL}.

The charging and discharging time of C_{INS} can be approximated as:

$$t_{charging} = -R_{eq} \cdot C_{INS} \cdot \ln\left(\frac{V_{BUS} \cdot \frac{R_{eq}}{R_{INS1}} + I_{INST} \cdot R_{eq} - V_{INSH}}{V_{BUS} \cdot \frac{R_{eq}}{R_{INS1}} + I_{INST} \cdot R_{eq} - V_{INSL}} \right)$$

$$t_{dicharging} = -R_{eq2} \cdot C_{INS} \cdot \ln\left(\frac{V_{BUS} \cdot \frac{R_{eq2}}{R_{INS1}} - V_{INSL}}{V_{BUS} \cdot \frac{R_{eq2}}{R_{INS1}} - V_{INSH}} \right)$$

where R_{eq} is the equivalent resistance for paralleling of R_{INS1} and R_{INS2},

$$R_{eq} = R_{INS1} \,//\, R_{INS2}$$

R_{eq2} is the equivalent resistance for paralleling of R_{INS1}, R_{INS2} and R_{Q3} (900ohm typically).

$$R_{eq2} = R_{INS1} \,//\, R_{INS2} \,//\, R_{Q3}$$

I_{INST} is an internal constant current source I_{INST}=680µA.

V_{INSL} and V_{INSH} is the min. and max voltage at VINS pin: V_{INSL}=0.5V, V_{INSH}=4.5V.

For example, if assume R_{INS1}=5MΩ, R_{INS2}=22kΩ, then $t_{charging}$=158µs, $t_{discharging}$=44µs.

IC will repeat the charging and discharging process for N_{OLP_R} times (N_{OLP_R}=2048). After that, IC will turn off the switches for both charging and discharging. In addition, the current source for hysteresis will be turned on and another blanking time of T_{BL_VINS} (T_{BL_VINS}=20ms) will be added so that VINS pin fully recovers and represents the bus voltage information. IC will start the soft start after the additional blanking time in case V_{VINS} is higher than the V_{VINSon}.

The total restart time can be calculated as:

$$t_{restart} = 2048 \cdot \left(t_{charging} + t_{discharging}\right) + 20ms$$

7.4 Mains Under Voltage Protection

The working range of mains input voltage needs to be specified for LLC resonant converter. It is important for the controller to have input voltage sensing function and protection feature, which allow the IC to stop switching when the input voltage drops below the specified range and restart with soft start when the input voltage resumes to its normal level. The mains input voltage sensing circuit is shown in product datasheet [1]. Thanks to the internal current source I_{hys} (12µA) connected between VINS pin and Ground, an adjustable hysteresis between the on and off threshold of mains input voltage can be created as:

$$V_{hys} = R_{INS1} \cdot I_{hys}$$

The mains input voltage is divided by R_{INS1} and R_{INS2}. If the on and off threshold for mains input voltage is V_{mainon} and $V_{mainoff}$, the resistors R_{INS1} and R_{INS2} can be selected as:

$$R_{INS1} = \frac{V_{mainon} - V_{mainoff}}{I_{hys}}, \qquad R_{INS2} = R_{INS1} \cdot \frac{V_{VINSon}}{V_{mainoff} - V_{VINSon}}$$

where I_{hys}=12µA, V_{VINSon}=1.25V.

For example, if R_{INS1}=5MΩ and R_{INS2}=22kΩ, the calculated V_{mainon}=345V, $V_{mainoff}$=285V.

7.5 Open Load Protection

At very light load condition, eg. open load, the designed maximum frequency may not be high enough to regulate the output voltage, the output voltage may loss control and cause damages. In order to avoid this issue, the feedback signal V_{FB} is continuously monitored. When V_{FB} drops below V_{FB_off} (typical 0.2V), the switching signal is disabled after a fixed blanking time, T_{FB} (typical 200ns). V_{FB} will then rise as V_{OUT} starts to decrease due to no switching signal. Once V_{FB} exceeds the threshold V_{FB_on} (typical 0.3V), IC resumes to normal operation.

8 Circuit Diagram and Components List

8.1 Schematics

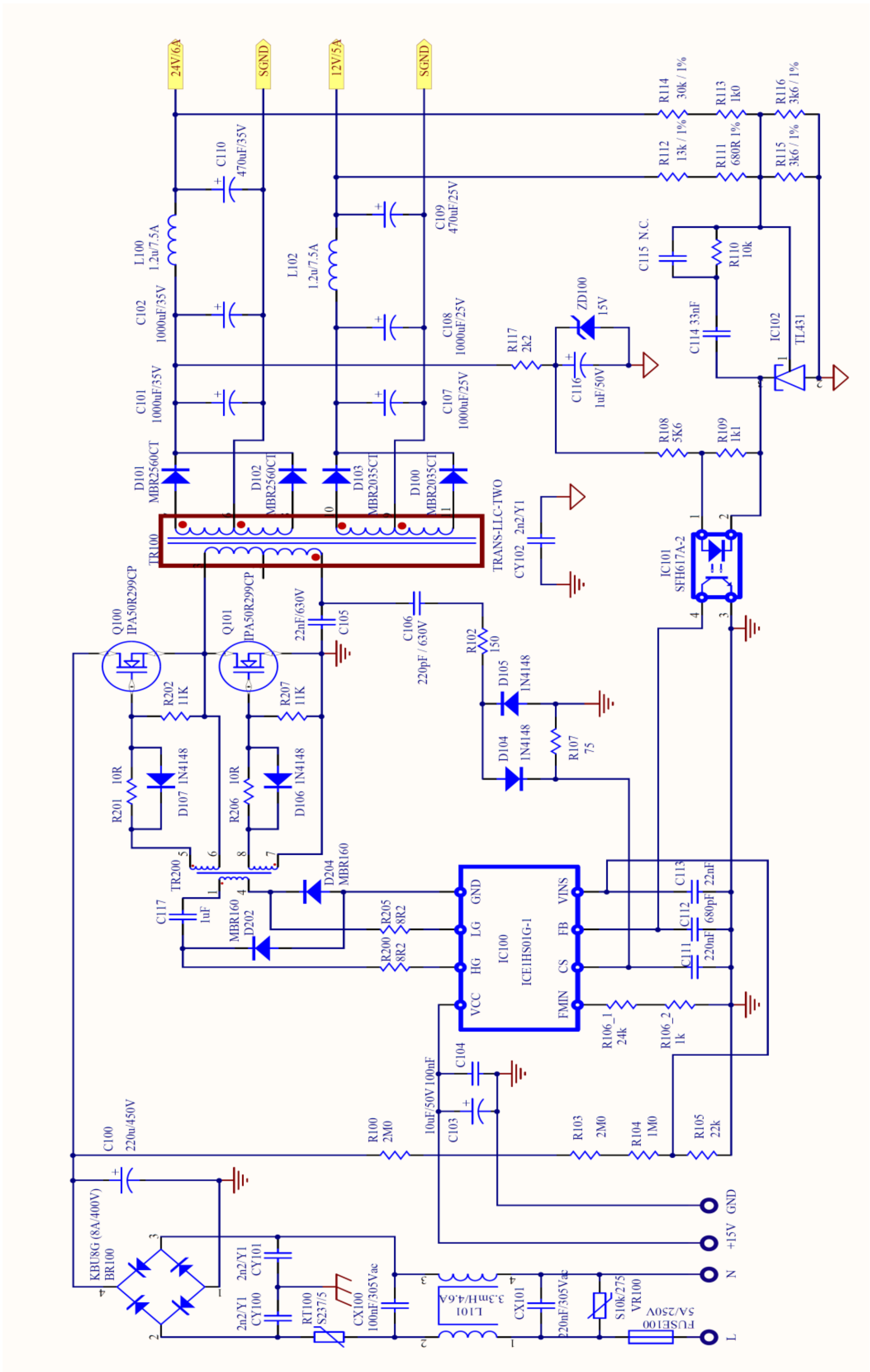

Figure 7 Schematics **of 200W half bridge LLC resonant**

8.2 PCB Layout

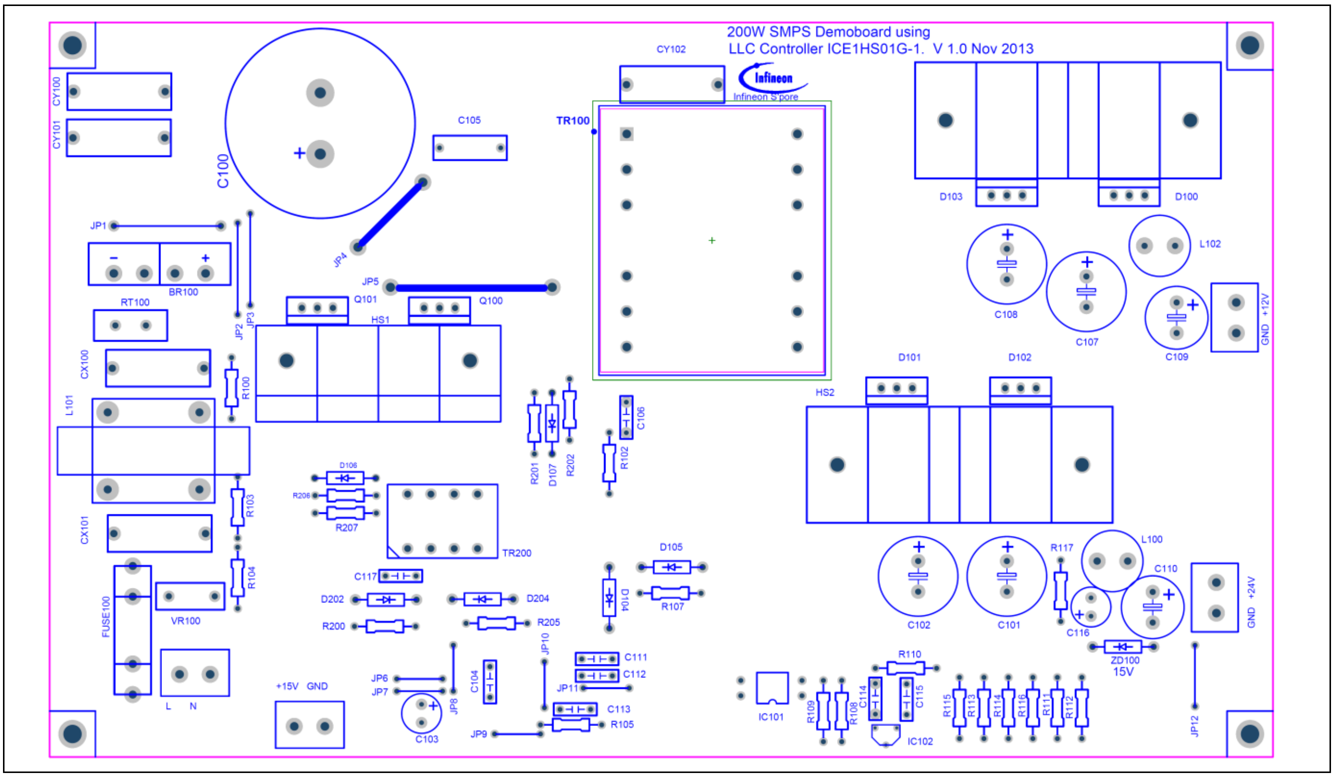

Figure 8 Component side - View from component side

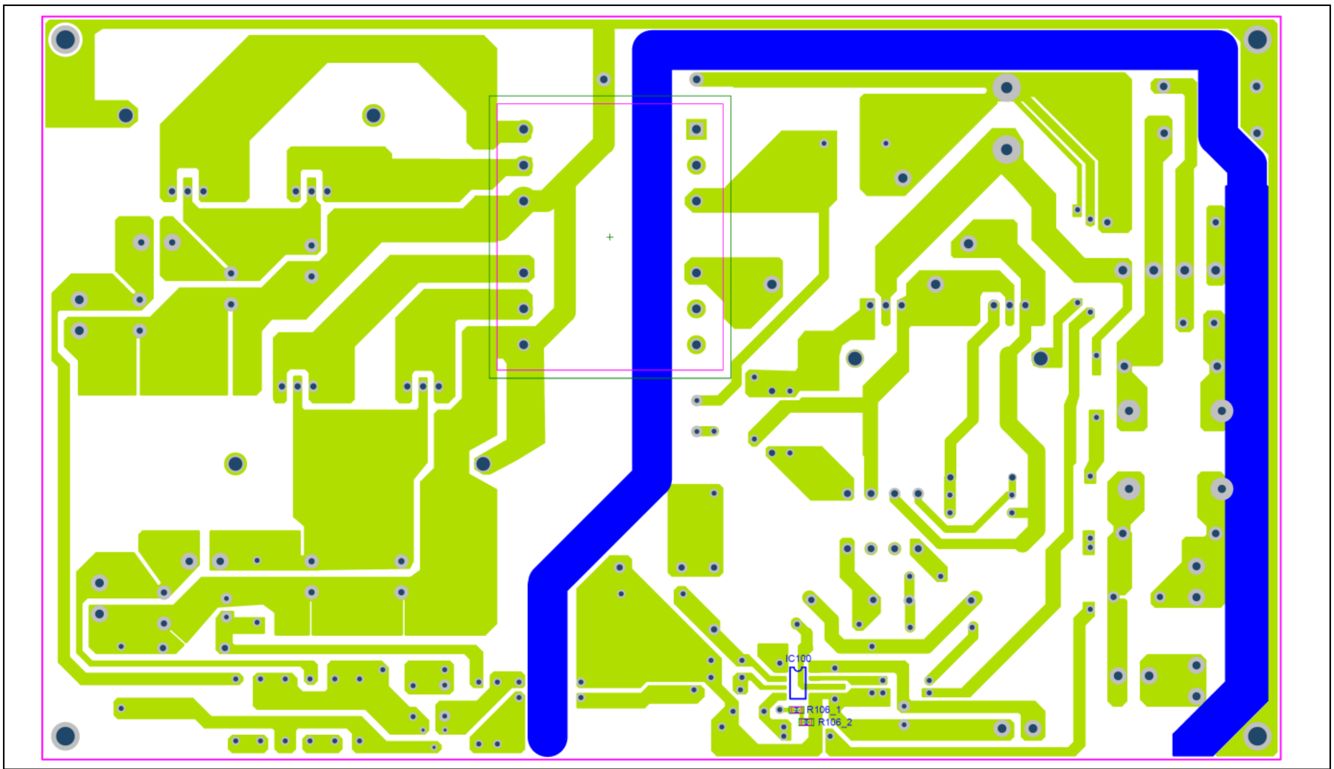

Figure 9 Solder side - View from solder side

8.3 Components List

Table 3 Bill of Materials

Item	Circuit code	Part value	Description	Supplier / Part No.
1	BR100	KBU8G (8A / 400V)	BRIDGE RECTIFIER	
2	C100	220µF/450V	Aluminum Electrolyte	EPCOS / B43304C5227M000
3	C101	1000µF/35V	Aluminum Electrolyte	
4	C102	1000µF/35V	Aluminum Electrolyte	
5	C103	10µµF/50V	Aluminum Electrolyte	EPCOS / B41821A6106M000
6	C104	100nF/50V	CERAMIC	
7	C105	22nF/630V	CERAMIC	EPCOS / B32621A6223J000
8	C106	220pF / 630V	CERAMIC	
9	C107	1000µF/25V	Aluminum Electrolyte	
10	C108	1000µF/25V	Aluminum Electrolyte	
11	C109	470µF/25V	Aluminum Electrolyte	
12	C110	470µF/35V	Aluminum Electrolyte	
13	C111	220nF/50V	CERAMIC	
14	C112	680pF/50V	CERAMIC	
15	C113	22nF/50V	CERAMIC	
16	C114	33nF/50V	CERAMIC	
17	C115	N.C.	CERAMIC	
18	C116	1µF/50V	Aluminum Electrolyte	
19	C117	1µF/50V	CERAMIC	
20	CX100	100nF/305 V_{AC}	CERAMIC	
21	CX101	220nF/305 V_{AC}	CERAMIC	EPCOS / B32922C3224K000
22	CY100	2n2/500Vac Y1	CERAMIC	EPCOS / B81123C1222M000
23	CY101	2n2/500Vac Y1	CERAMIC	EPCOS / B81123C1222M000
24	CY102	2n2/500Vac Y1	CERAMIC	EPCOS / B81123C1222M000
25	D100	MBR2035CT	SCHOTTKY DIODE	Vishay / MBR2035CT
26	D101	MBR2560CT	SCHOTTKY DIODE	Vishay / MBR2560CT
27	D102	MBR2560CT	SCHOTTKY DIODE	Vishay / MBR2560CT
28	D103	MBR2035CT	SCHOTTKY DIODE	Vishay / MBR2035CT
29	D104	1N4148	DIODE	
30	D105	1N4148	DIODE	
31	D106	1N4148	DIODE	
32	D107	1N4148	DIODE	
33	D202	MBR160	SCHOTTKY DIODE	
34	D204	MBR160	SCHOTTKY DIODE	
35	FUSE100	5A/250V	RESISTOR FUSE	
36	IC100	ICE1HS01G-1	Resonant-Mode	INFINEON / ICE1HS01G-1

			Controller	
37	IC101	SFH617A-2	OPTO COUPLER	
38	IC102	TL431	ERROR AMPLIFIER	
39	L100	1.2µH/7.5A	CHOKE	
40	L101	3.3mH/4.6A	COMMON MODE CHOKE	EPCOS / B82734R2462B30
41	L102	1.2µH/7.5A	CHOKE	
42	Q100	IPA50R299CP	POWER MOSFET	INFINEON / IPA50R299CP
43	Q101	IPA50R299CP	POWER MOSFET	INFINEON / IPA50R299CP
44	R100	2M /1%	RESISTOR	
45	R102	150R	RESISTOR	
46	R103	2M / 1%	RESISTOR	
47	R104	1M / 1%	RESISTOR	
48	R105	22k / 1%	RESISTOR	
49	R106_1	24k / 1%, 0805	RESISTOR	
50	R106_2	1k / 1%	RESISTOR	
51	R107	75R	RESISTOR	
52	R108	5k6	RESISTOR	
53	R109	1k1	RESISTOR	
54	R110	10k / 1%	RESISTOR	
55	R111	680R / 1%	RESISTOR	
56	R112	13k / 1%	RESISTOR	
57	R113	1k0 / 1%	RESISTOR	
58	R114	30k / 1%	RESISTOR	
59	R115	3k6 / 1%	RESISTOR	
60	R116	3k6 / 1%	RESISTOR	
61	R117	2k2	RESISTOR	
62	R200	8R2	RESISTOR	
63	R201	10R	RESISTOR	
64	R202	11K	RESISTOR	
65	R205	8R2	RESISTOR	
66	R206	10R	RESISTOR	
67	R207	11K	RESISTOR	
68	RT100	S237/5	Thermister	EPCOS / B57237S509M000
69	TR100	TRANS-LLC-TWO	LLC Transformer	Wurth Electronics Midcom Inc. (Model:750342784)
70	TR200	Pulse Transformer	Pulse transformer	Wurth Electronics Midcom Inc. (Model:750342109)
71	VR100	S10k/275	VDR	EPCOS / B72210S271K101
72	ZD100	15V	Zener diode	
73	JP1, JP2, JP3, JP4, JP5, JP6,	Jumper	Jumper	

	JP7, JP8, JP9, JP10, JP11, JP12			
74	HS1	For Q100, Q101	Heatsink	
75	HS2	For D101, D102	Heatsink	
76	HS3	For D100, D103	Heatsink	
77	CN1	For AC	2-pin connector	
78	CN2	For 15V	2-pin connector	
79	CN3	For 12V	2-pin connector	
80	CN4	For 24V	2-pin connector	

9 Transformer Construction

9.1 Mains Transformer

- Bobbin: type ER34
- Core: TP4 ER34 from TDG
- Primary inductance: 636µH±5%, Gapped between Pin3 and Pin5 (measured at 50kHz)
- Leakage inductance: 100µH±5%, measured between Pin3 and Pin5 by shorting (Pin 8 & 10 and Pin 12 &14) or (Pin 8& 9 and Pin 12 & 13) (measured at 100kHz)
- Manufacturer and part number : Wurth Electronics Midcom 750342784

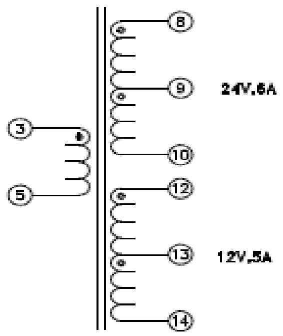

Figure 10 LLC resonant transformer electrical diagram

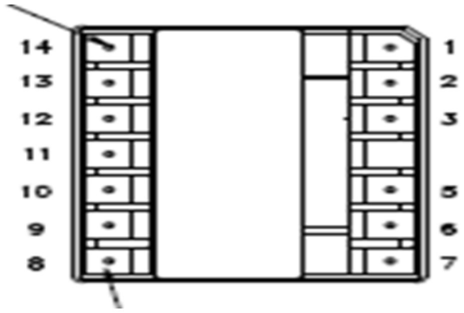

Figure 11 LLC resonant transformer complete – bottom view

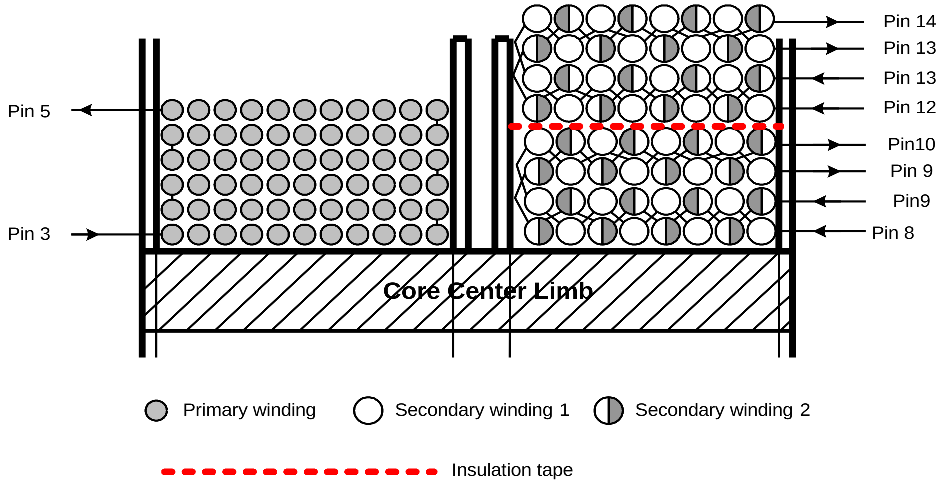

Figure 12 LLC resonant transformer winding position

Table 4 **LLC resonant transformer winding characteristics**

Pins	winding	turns	wire
3~5	primary	34	7*0.20
8~9	Secondary 1	4	19*0.20
9~10	Secondary 2	4	19*0.20
12~13	Secondary 3	2	19*0.20
13~14	Secondary 4	2	19*0.20

9.2 Pulse Transformer

- Bobbin: E16/8/5, Vertical version from TDG
- Core: E16/8/5 TP4 from TDG
- Manufacturer and part number : Wurth Electronics Midcom 750342109

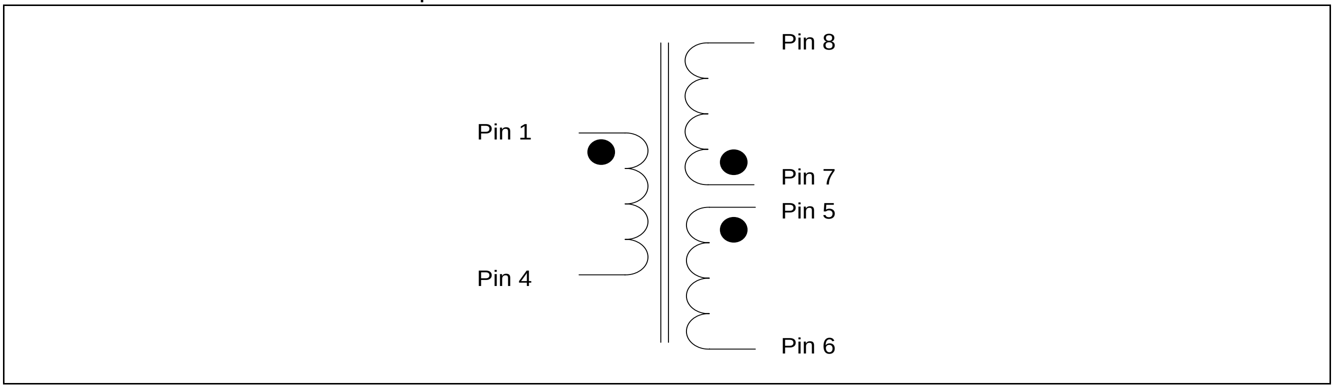

Figure 13 Pulse Transformer electrical diagram

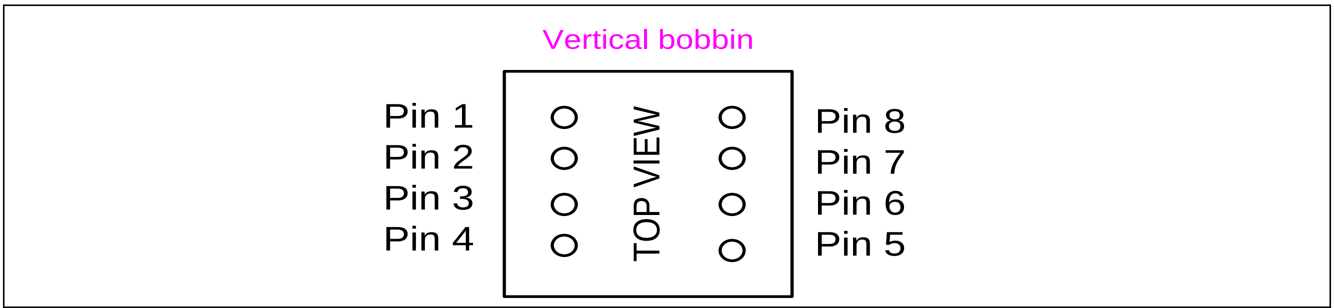

Figure 14 Pulse transformer complete – top view

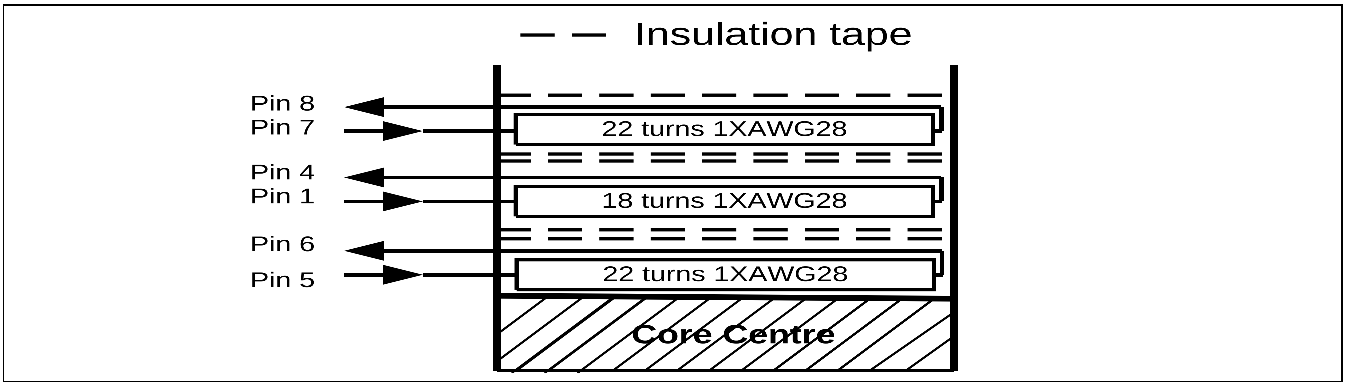

Figure 15 Pulse transformer winding position

10 Electrical Test Results

10.1 Efficiency Measurements

Table 5 shows the output voltage measurements at the nominal input voltage 380 V_{DC}, with different load conditions. The input voltage 380 V_{DC} is supplied from a high voltage DC power supply.

Table 5 Efficiency measurements @ input voltage =380 V_{DC}

Load(%)	V_{out1}(V)	I_{out1}(A)	V_{out2}(V)	I_{out2}(A)	P_{out}(W)	V_{in}(V)	I_{in}(A)	P_{in}(W)	V_{CC}(V)	I_{vcc}(A)	Pvcc(W)	Eff.(%)
100%	24.02	6.01	11.80	5.00	203.31	379.9	0.57	216.20	14.18	0.0199	0.28	93.91%
82%	23.99	5.00	11.82	4.00	167.30	379.9	0.47	177.53	14.18	0.0200	0.28	94.09%
65%	23.96	4.00	11.83	3.01	131.45	379.9	0.37	139.39	14.18	0.0202	0.29	94.11%
50%	23.97	3.01	11.82	2.50	101.77	379.9	0.28	108.04	14.18	0.0203	0.29	93.94%
47%	23.93	3.01	11.84	2.00	95.83	379.9	0.27	101.78	14.18	0.0203	0.29	93.90%
29%	23.89	2.01	11.86	1.00	59.89	379.9	0.17	64.13	14.18	0.0205	0.29	92.98%
20%	23.93	1.20	11.84	1.00	40.57	379.9	0.12	44.14	14.18	0.0206	0.29	91.30%
15%	23.89	1.01	11.86	0.51	30.08	379.9	0.09	33.17	14.18	0.0207	0.29	89.90%
10%	23.92	0.60	11.84	0.51	20.35	379.9	0.06	23.36	14.18	0.0207	0.29	86.00%
5%	23.90	0.30	11.85	0.25	10.15	379.9	0.03	12.88	14.18	0.0208	0.30	77.02%

The power losses due to IC and driver circuit are both included. In addition, the efficiency values were measured after 30 minutes of warm-up at full load.

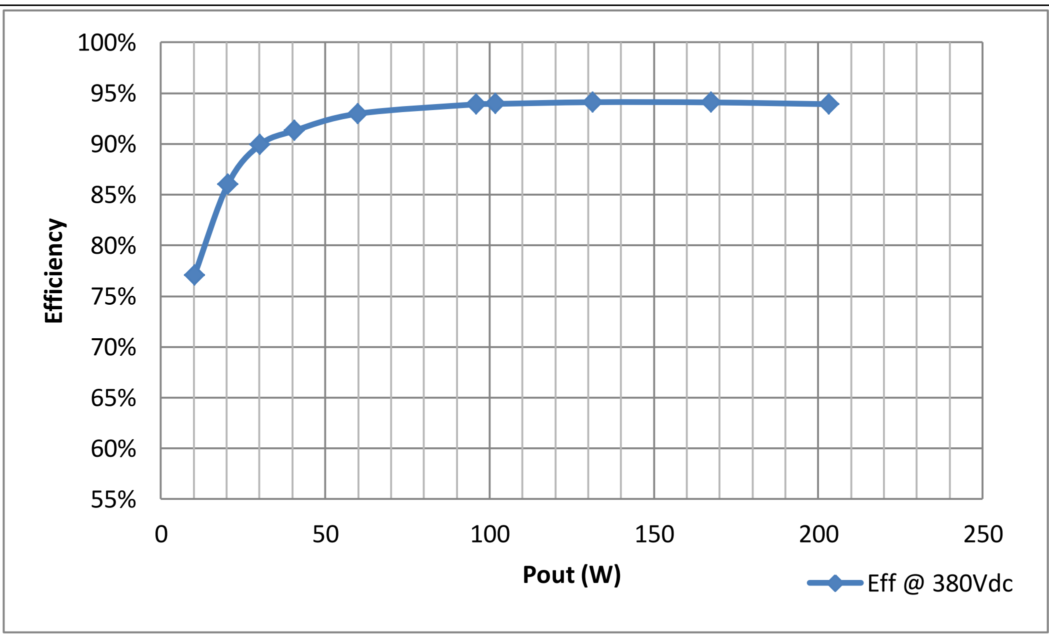

Figure 16 LLC stage efficiency

10.2 Zero Voltage Switching

The LLC system can achieve ZVS over a very wide range of load.

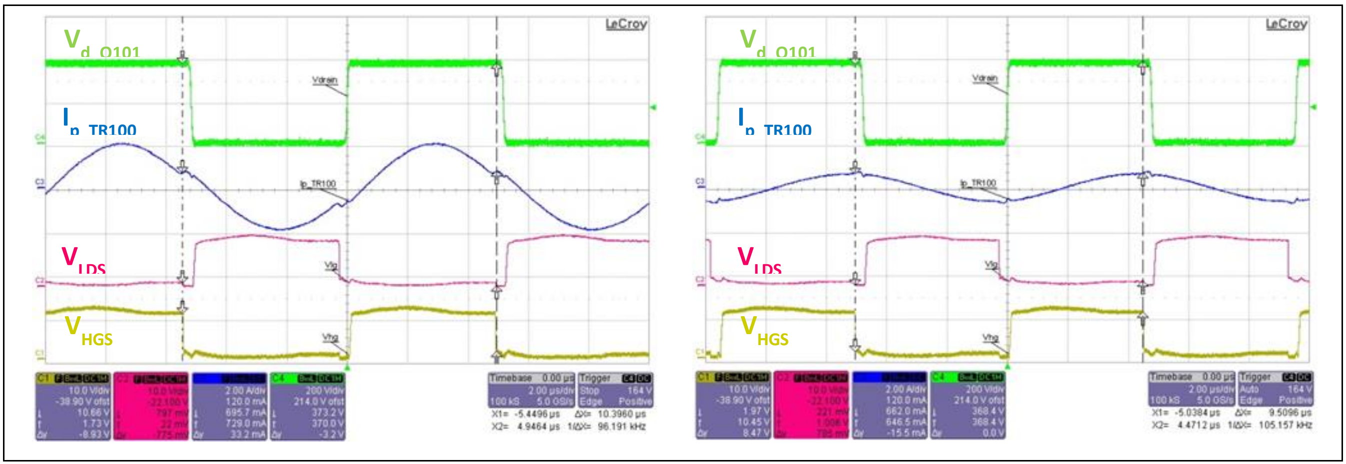

Figure 17 Zero Voltage switching (Left: @ 380 V_{DC} input voltage and 100% full load, Right : @ 380 V_{DC} input voltage and 10% full load)

10.3 Soft Start

During start-up at full load or no load, the primary resonant current is strictly limited, and the 24 V output voltage smoothly rises to its regulated value. The overshoot is less than 10%, the start-up time is less than 30ms.

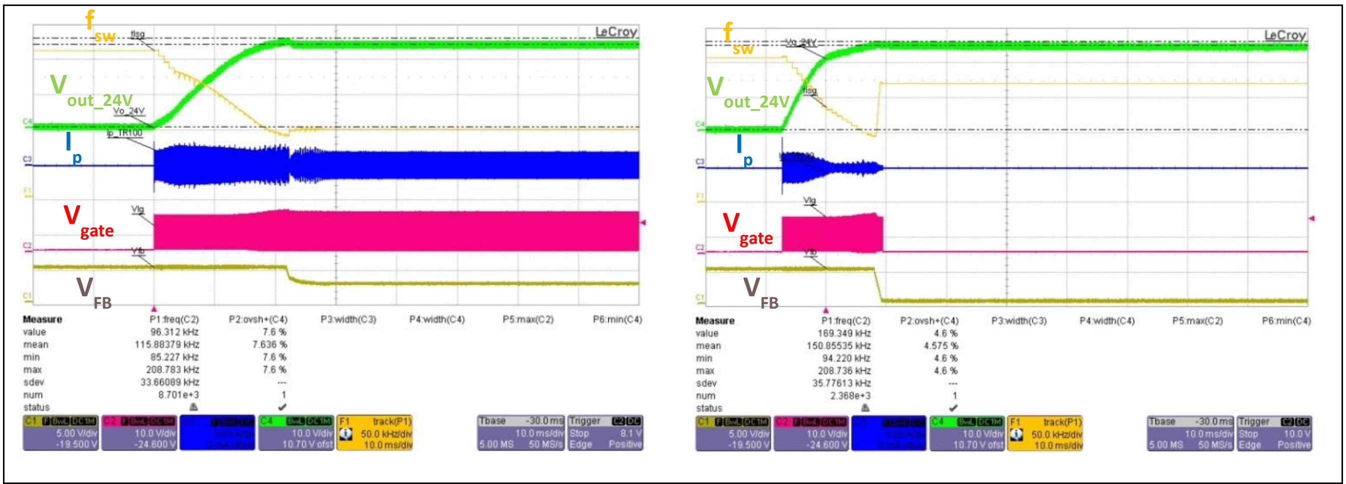

Figure 18 Soft start at full load and no load (Left: Soft start @ 380 V_{DC} input voltage and full load, Right : Soft start @ 380 V_{DC} input voltage and no load)

10.4 Over Current Protection

Figure 19 shows the over current protection. Two kinds of OCP are avilable. The 1st is V_{CS} > 0.8 V and the switching frequency increase according to the exceeded duration. Then it would return to normal switching frequency when V_{CS} < 0.75 V (left side waveform). The 2nd one is VCS > 1.6 V, the system enters latch mode (right side waveform).

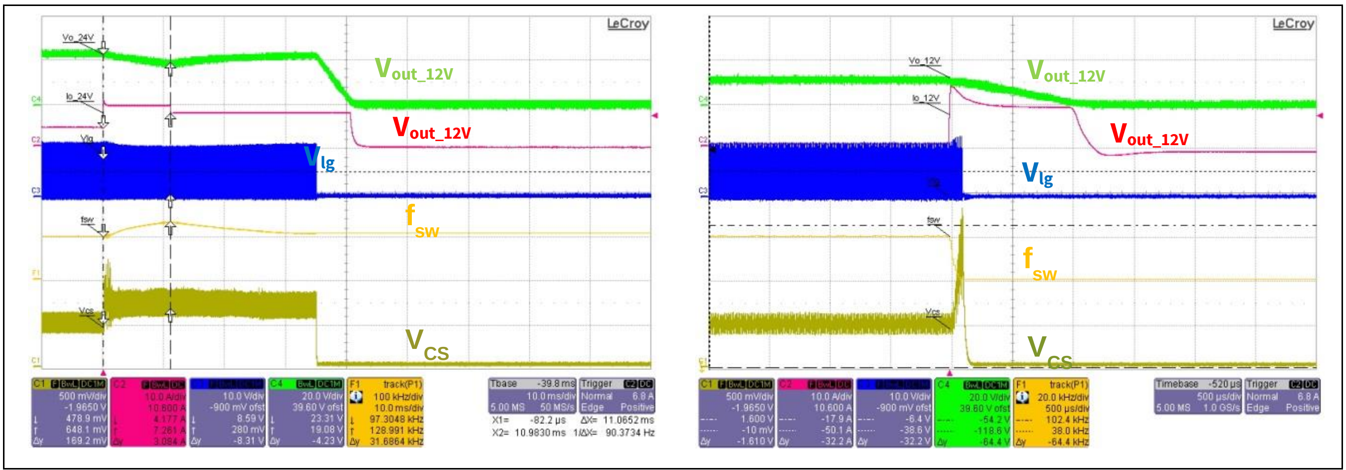

Figure 19 Over Current Protection (Left : 12 V @ 5 A, 24 V @ 6 A – 9 A - switching frequency increase when V_{CS} > 0.8 V and then drop to normal when V_{CS} < 0.75 V. The system enters AR after over load protection reached. Right : 24 V @ 6 A, 12 V short circuit - system enter OCP latch mode when the V_{CS} > 1.6 V.)

10.5 Over Load Protection

Blanking time in case of over load protection can be adjusted as discussed before, the charging time t_{chg_olp} and discharging time t_{dischg_olp} of C_{FB} is 31.6μs and 1.62μs respectively, this measured result is closely equal to the calculated result which is mentioned at section 7.3.

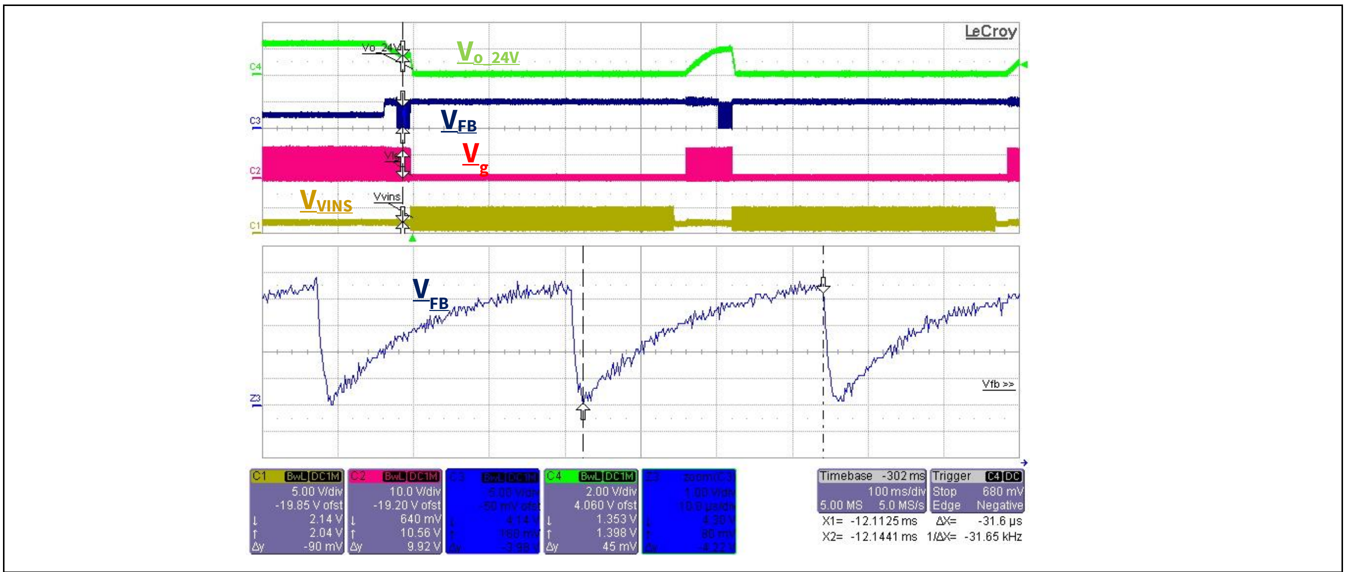

Figure 20 Adjustable extended blanking time in case of over load protection

Restart time in case of over load protection can also be adjusted as discussed before, the charging time t_{charge} and discharging time $t_{discharge}$ of C_{vins} is 118.4μs and 51.8μs respectively, this measured result is closely equal to the calculated result which is mentioned at section 7.3.

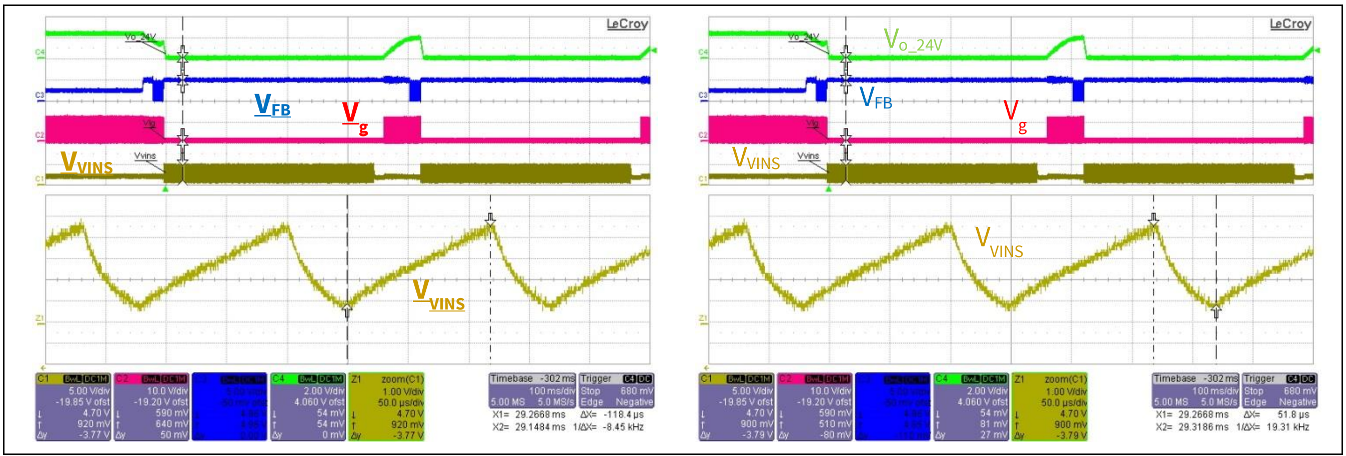

Figure 21 **Adjustable restart time in case of over load protection (Left : C_{VINS} charging time, Right : C_{VINS} discharging time)**

10.6 Output Short Circuit Protection

When the output load is short circuit, V_{FB} jumps to a higher value. When this condition lasts longer than the internal fixed blanking time 20ms, the extended adjustable blanking time will be initiated. After these two blanking times the IC will enter restart mode and stops switching if the short circuit condition still exists. After an adjustable restart time plus an internal fixed restart time 20ms, the IC resumes to normal operation with soft start. During soft start, the over load protection is disabled. When soft start process completed, if the output short circuit condition still exists, IC will enter auto restart mode again. When the output short circuit condition disappears, IC will resume to normal operation and the 24 V output voltage is established again.

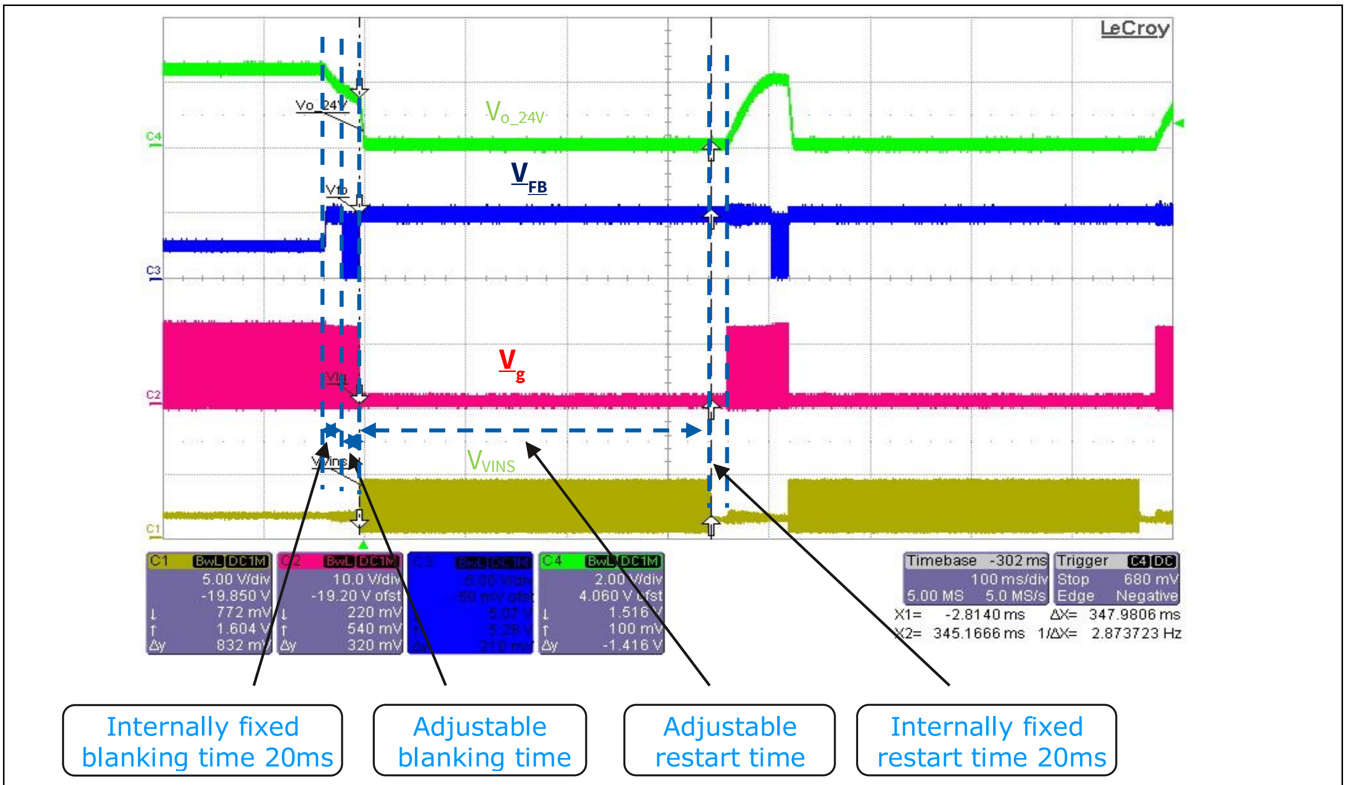

Figure 22 **Output short circuit protection**

10.7 Mains Under Voltage Protection

When V_{bus} drops lower than 285 V_{DC}, IC stops switching; When V_{bus} rises up to 356 V_{DC}, IC starts normal operation after a 500.8us blanking time. These measured results are closely equal to the calculated results mentioned at section 7.4.

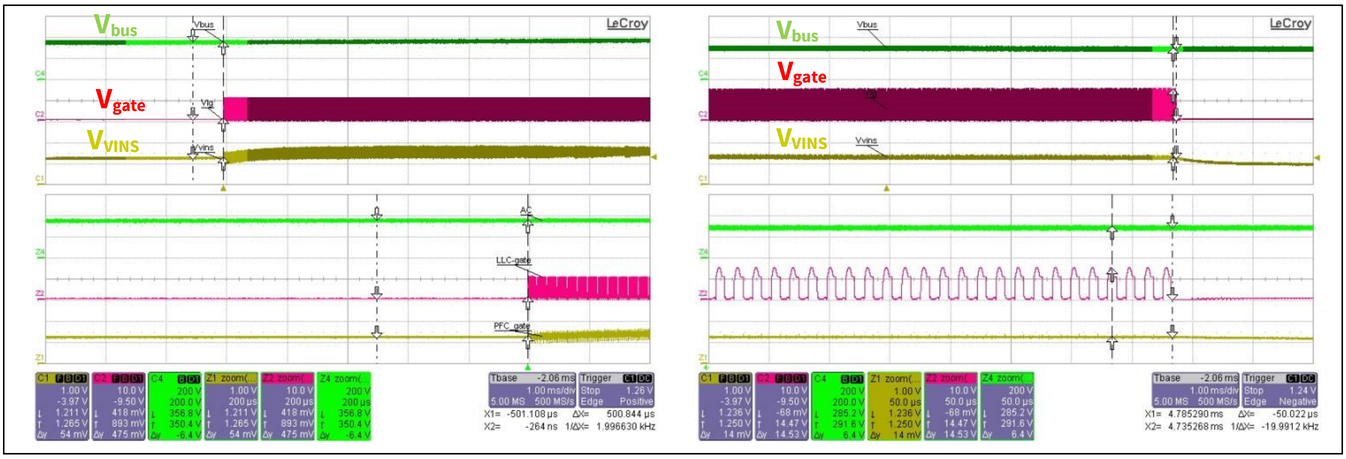

Figure 23 Mains under voltage protection (Left : IC starts operation when Vbus resumes to normal value, Right : IC stops switching when Vbus drops to designed value)

10.8 Burst Mode Operation at No Load

Burst mode operation is implemented in ICE1HS01G-1 to avoid possible over output voltage issue in case of light load or no load operation. When V_{FB} drops below V_{FB_off} (measured value 0.180 V), the switching signal will be disabled. V_{FB} will then rise as Vout starts to decrease due to no switching signal. Once V_{FB} exceeds the threshold V_{FB_on} (measured value 0.285 V), IC resumes to normal operation.

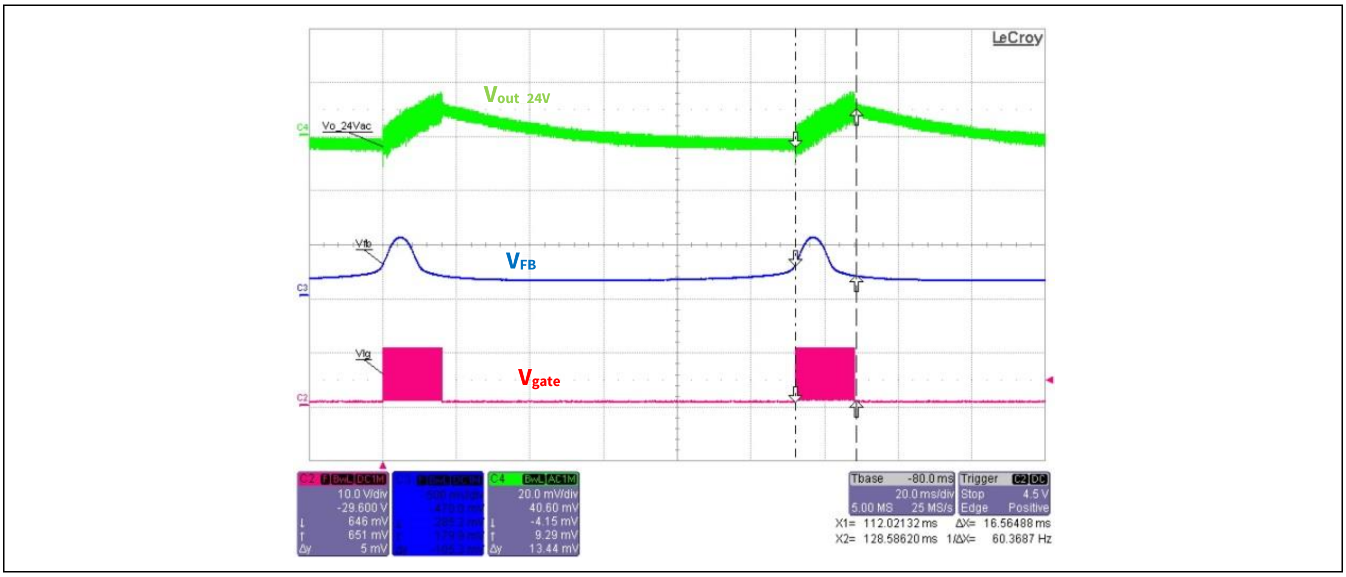

Figure 24 Burst mode operation

10.9 Dynamic Load Response

Figure 25 shows the dynamic behavior of this demo board during a load variation from around 10% to 100% full load on one output, with the other output at its full load. The output voltage ripple of 24 V and 12 V are both less than 5%.

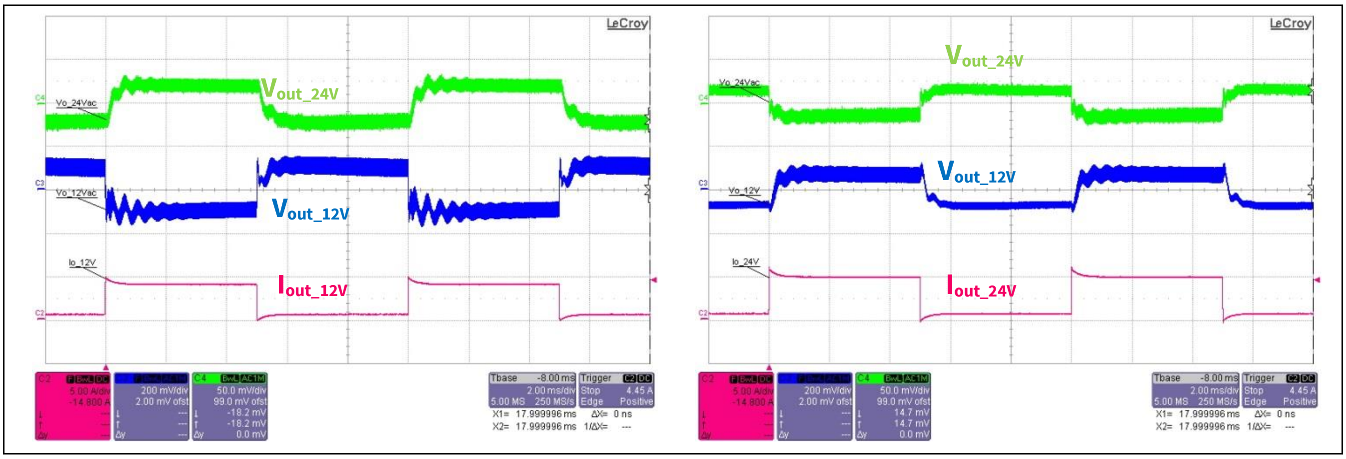

Figure 25 Dynamic load response (Left : 24 V @ 6 A, 12 V @ 0.5 A – 5 A, Right : 24 V @ 0.5 A - 6 A, 12 V @ 5 A)

11 References

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Revision History

Major changes since the last revision

Page or Reference	Description of change
12, 13, 14, 15, 16	Revise schematic value, add PCB solder side legend and revise BOM typo

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