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Wide-range High Voltage Input LLC Auxiliary Power Supply

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Abstract

For power electronic converter systems of medium-high voltage and large capacity, using of high-voltage and wide-range DC/DC auxiliary power supply (APS) in secondary circuits is essential for these systems' secure operation. However, The existing APS which mostly adopt flayback structure are mainly designed for low-voltage, small power converter systems, lower efficiency, power density, power level and is vulnerable to interference. Therefore, we designed a DC/DC APS for medium voltage, large power converter systems. The APS could work with input of 450-1000V and output of 24V output. It adopts LLC structure that helps to realize the wide-range input and isolation, achieve soft switching at fixed high frequency. It would reduce the volume, improve the efficiency,realize electrical isolation and avoid the mutual interference. In this paper, The working principle and control in the circuit were described in detail. Feasibility of new auxiliary power last verified by a prototype.

Keywords

Auxiliary Power Supply; High-Voltage Input; Wide-Range; LLC; Stability High Step-Down Ratio Technology.

1. Introduction

In the design of power converters, the requirements for increasing power density and reducing design size are getting higher and higher, and designers are urgently required to increase the switching frequency. The use of high-frequency operation will greatly reduce the size of passive components, but the existing switching loss and serious EMI problems will adversely affect high-frequency operation. Using the LLC topology, the converter works in a soft switching state, and the switching loss and noise can be greatly reduced. The auxiliary power module designed with the LLC topology can reduce the interference to the equipment.

With the the low carbonization of the energy structure , the DC microgrid has eveloped rapidly . In the low voltage DC distribution network, there are different levels of bus voltage, through a number of converters step-down mode for load power supply. In order to improve the energy transmission efficiency in the DC microgrid,the research of DCI/DC converter with higher step-down ratio and higher efficiency has important significance. We need a high-transformation ratio auxiliary power supply connected to the high-voltage DC bus. In this paper, to overcome the shortcomings we need we adopt the LLC topology with a new control strategy. Ti's Ucc256304 control chip performs well in this regard. UCC256304 uses hybrid hysteretic control to provide best in class line and load transient response. The control makes the open loop transfer function a first order system so that it's very easy to compensate and is always stable with proper frequency compensation. However, the high-voltage performance of this chip is very poor. For this, we designed a set of isolated drive circuit to effectively solve this problem. Which increase the usage conditions from 500V to 1000v.This paper introduces hardware circuit design and device selection. The structure and winding arrangement of the planar transformer are optimized. Simulation experiments are conducted to verify the correctness

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of the design scheme. Under limited experimental conditions, an experimental prototype with a switching frequency of 500 kHz and an output power of 48W is built and debugged. The rated output voltage can achieve 12V, with ripple 500mV. The system efficiency reaches94.8% at full load, which reaches the design targe.

2. Half-Bridge LLC Converter Design

2.1 Half-Bridge LLC Converter Design

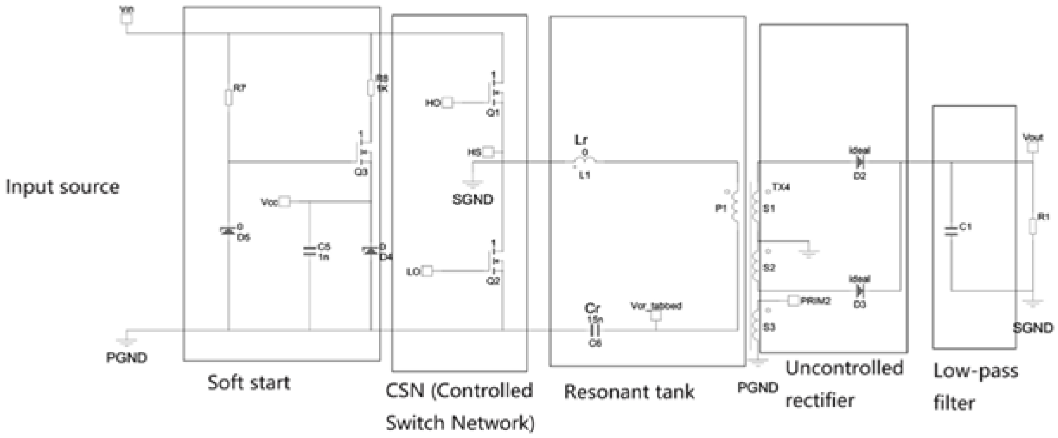

Fig. 1 Half bridge series resonat convweter

2.2 Soft star

As shown in Figure 1, the resistance value of the current limiting resistor Rst in the starting circuit is mach smaller than Rt. Rst can realize the fast start of the power supply at low voltage input after the power is turned on, the small resistance Rst is automatically turned off through Rt branch. So that the auxiliary power supply is working in the wide voltage input range Start-up, and the start-up circuit loss is small. when the switch tube Q2 is turned on, Uin charges the capacitor C2 via Rst and Q2, Ucc is greater than the starting voltage of the PWM chip UCA3844 (Figure 2), the power supply starts, and when the power supply is started, the rear-stage converter circuit starts to output voltage Ucc, Q2 shuts down.

2.3 LLC Resonant Converter design

Converter Parameters:

Table 1. Converter Parameters

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
INPUT CHARACTERISTICS					
input Voltage range		450	800	1000	VDC
Input DC current	Input = 450 VDC, full load = 10 A		0.459		A
Input DC current	Input = 800 VDC, full load = 10 A		0.279		A
Input DC current	Input = 1000VDC, full load = 10 A		0.24		A
OUTPUT CHARACTERISTICS					
Output voltage, VOUT	No load to full load		24		VDC
Output load current, IOUT	450VDC to 1000VDC			10	A
Output voltage ripple	800VDC and full load = 10 A		130		mVpp
SYSTEMS CHARACTERISTICS					
Switching frequency		160	200	300	kHz
Peak efficiency	800VDC		92.9		%
Operating temperature	Natural convection		25		°C

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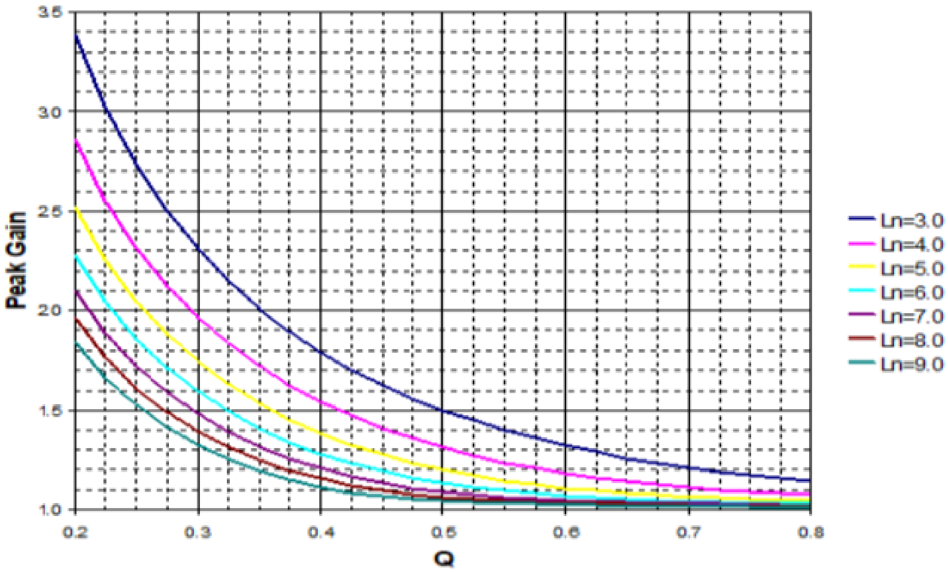

Fig. 2 Max-gain curve with Ln and Q

Thee quations and Parameters given below are based on the First Harmonic Approximation (FHA) method commonly used to analyze the LLC topology. This method gives a good starting point for any design, but a final design requires an iterative approach combining the FHA results, circuit simulation, and hardware testing. Using the FHA analysis method to analyze the data of Table 1, we can easily get to the following parameters.

1) Choose/Determine Q and Ln from M_pk (Q, Ln) curves

$$M_g = \left| \frac{L_n \times f_n^2}{[(L_n+1)\times f_n^2 - 1] + j[(f_n^2 - 1)\times f_n \times Q_e \times L_n]} \right| \quad (1)$$

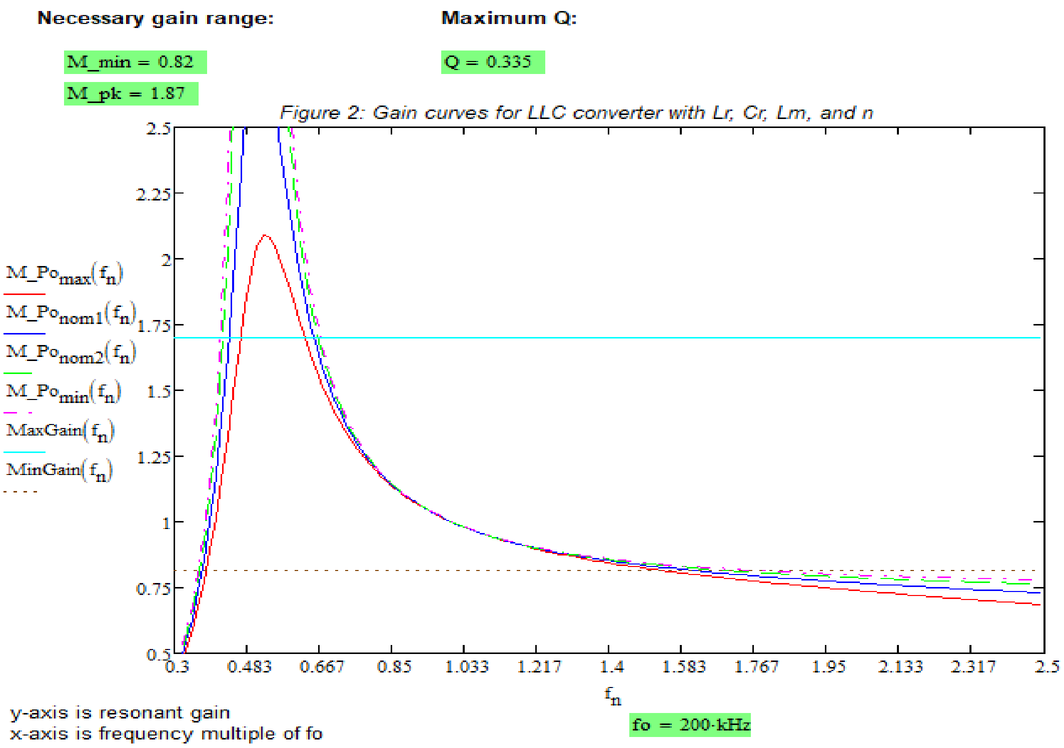

Fig. 3 Gain curve with Ln and Q

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Pre choose Q Typical range: 0.3 to 0.5

Q=0.375

At pre-chosen Q, pick the curve with the peak gain greater than or equal to M_pk.Refer to the curve corresponding to the 'Ln' value for further calculation.

From the curvers pick Ln=3

2) Calculate/Determine Resonant Components

Cr=4.4nF; Lr=144uH; Lm=432u

3) Calculate Gain Curves

Gain curves are shown in Fig. 3. Ensure necessary gain range is available for your maximum load, and it is in an acceptable frequency range. This set of curves is a simple model of llc resonant converter, which has guiding significance for the selection of parameters of resonant cavity. We can read the relationship between the reference variables from the image in the figure.

3. LLC driven design

Overview

An integrated high voltage JFET allows the power system to be regulating its output voltage within one second of the mains voltage appearing at the input of the PFC stage. UCC256304 provides start-up power for both the LLC and PFC stages. Once operating, the JFET is switched OFF to limit power dissipation in the package and reduce standby power consumption. At low output power levels UCC256304 automatically transitions into light-load burst mode. The LLC equivalent load current level during the burst on period is a programmable value. The space period between bursts is terminated by the secondary voltage regulator loop based on the FB pin voltage. During burst mode, the resonant capacitor voltage is monitored so that the first and last burst pulse widths are fully optimized for best efficiency. This method allows UCC256304 to achieve higher light-load efficiency and reduced no-load power compared with alternative parts. In addition, UCC256304 enables the opto-coupler to operate at a low power mode, which can save up to 20 mW at standby mode comparing with conventional solution. Additional protection features of UCC256304 include three-level over current protection, output over voltage protection, input voltage OVP and UVP, gate driver UVLO protection, and over temperature protection.

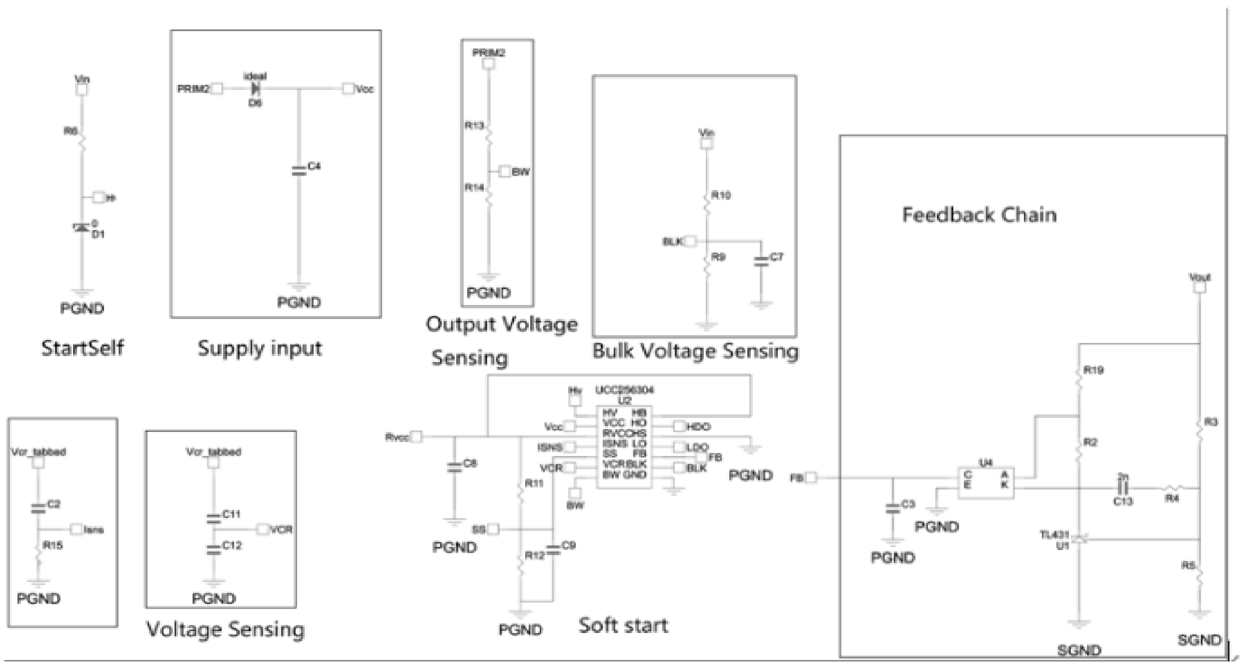

Fig. 4 Main control chip peripheral circuit

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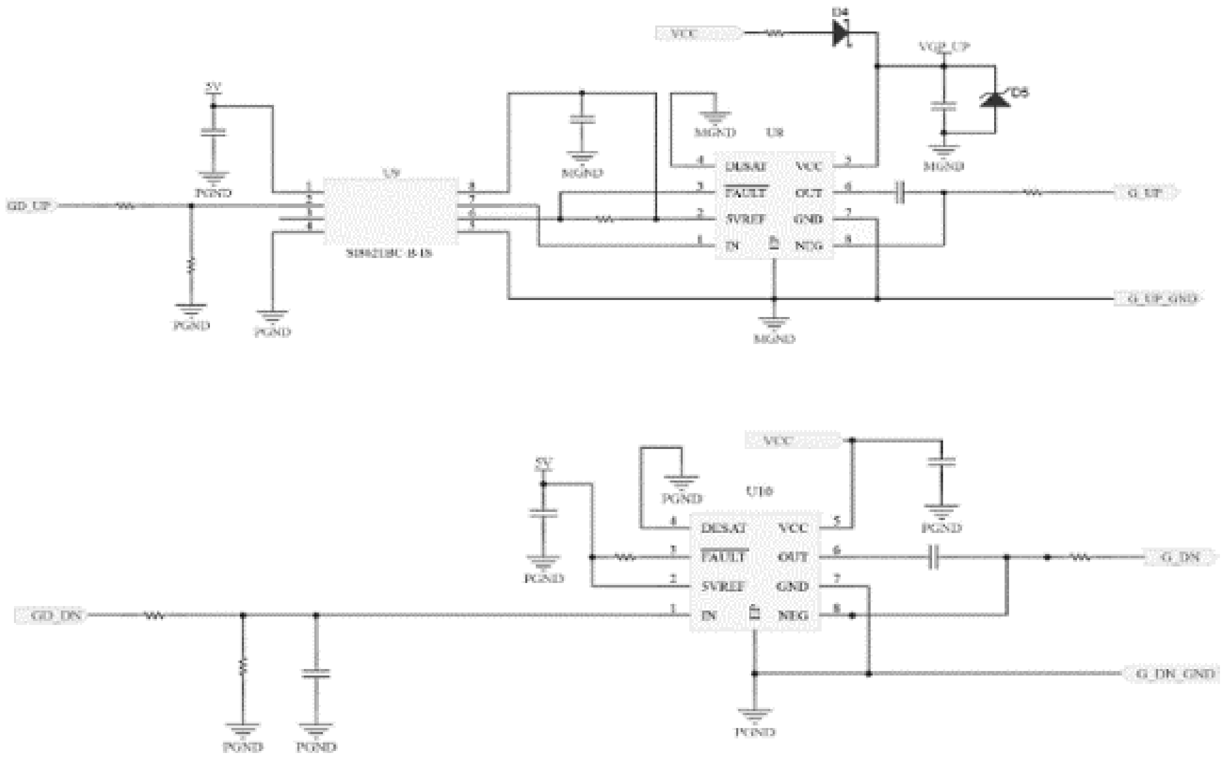

Fig. 5 Isolation chip peripheral circuit

As mentioned above, uc256304 has many advantages, especially in standby power consumption, HHC control strategy and Wide operating frequency range is excellent. It performance in high-voltage drive and soft start-up does not meet the design requirements of this time. It's bootstrap circuit can only withstand voltages below 600v, So in order to meet the high voltage input conditions of 1000v, we took the isolated drive and placed the bootstrap circuit behind the isolated drive chip.

4. Power Transformer design

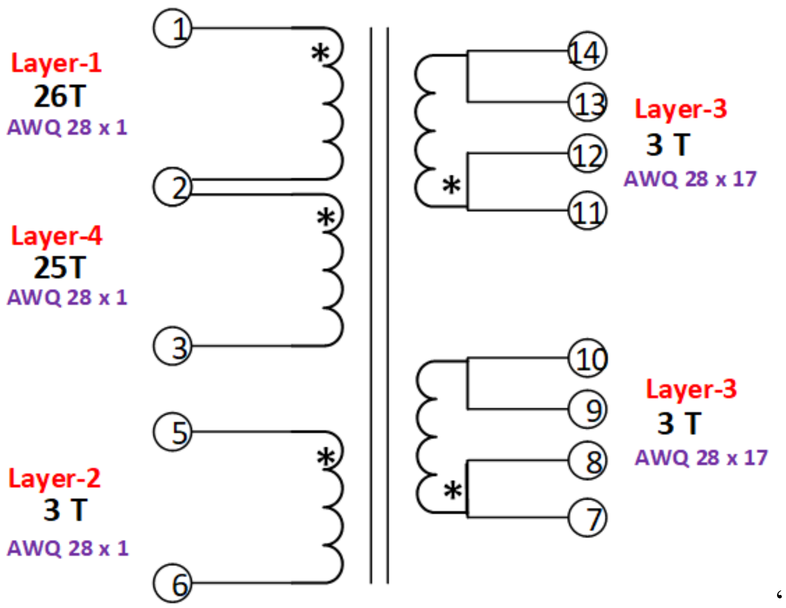

Fig. 6 Transformer winding

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A bias winding is needed in order to utilize the HV self start up function. It is recommended to design the bias winding so that the VCC voltage is greater than 13 V. The big advantage of llc resonant converter is that it integrates leakage inductance into the transformer, which greatly reduces the size of the power supply and increases the power density. Therefore, the design of the transformer is very important for the LLC resonant power supply, and the inaccuracy of the leakage inductance will inevitably lead to the disorder of the resonant cavity.Under the guidance of Dr. Yang Bo's thesis, we designed the transformer as shown on the right. His detailed parameters are as follows:

Magnetic Core: B65875B0000R095, TDK N95

14 Pin Bobbin: CPV-PS20/16-1S-14P-Z

Clamp: CLAMP-PQ20/16

Inductance between Pin-1 and 3 = 432uH+/-5% (other windings are open)

Primary Working voltage = 240V- 800V

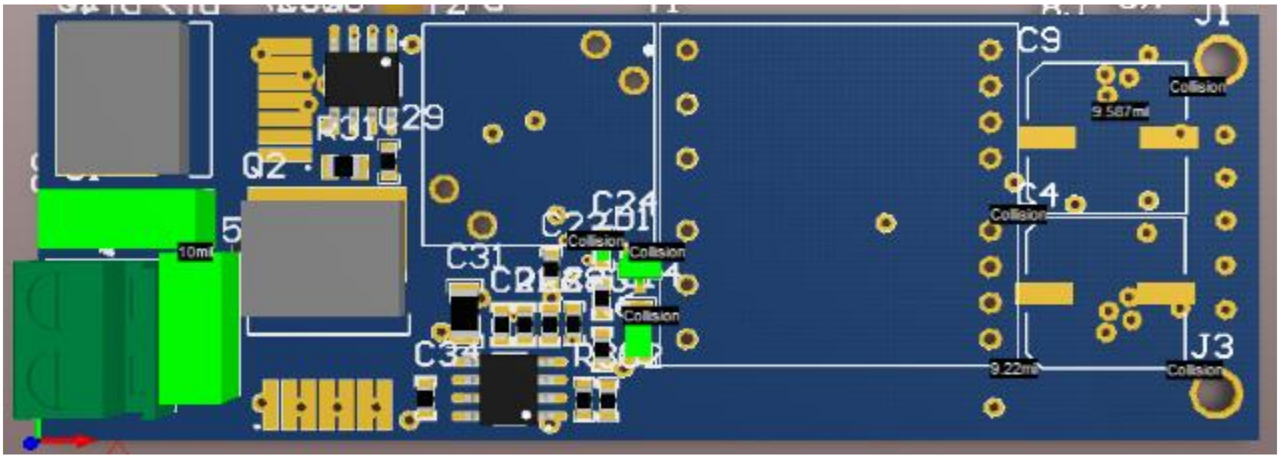
Switching frequency: 200kHz

Primary and Secondary isolation: 1500Vac

Primary (p1 and p2) to P3: 1000Vac

5. Test Result

In this part, the test result of wide-range high voltage input LLC auxiliary power supplys tested.



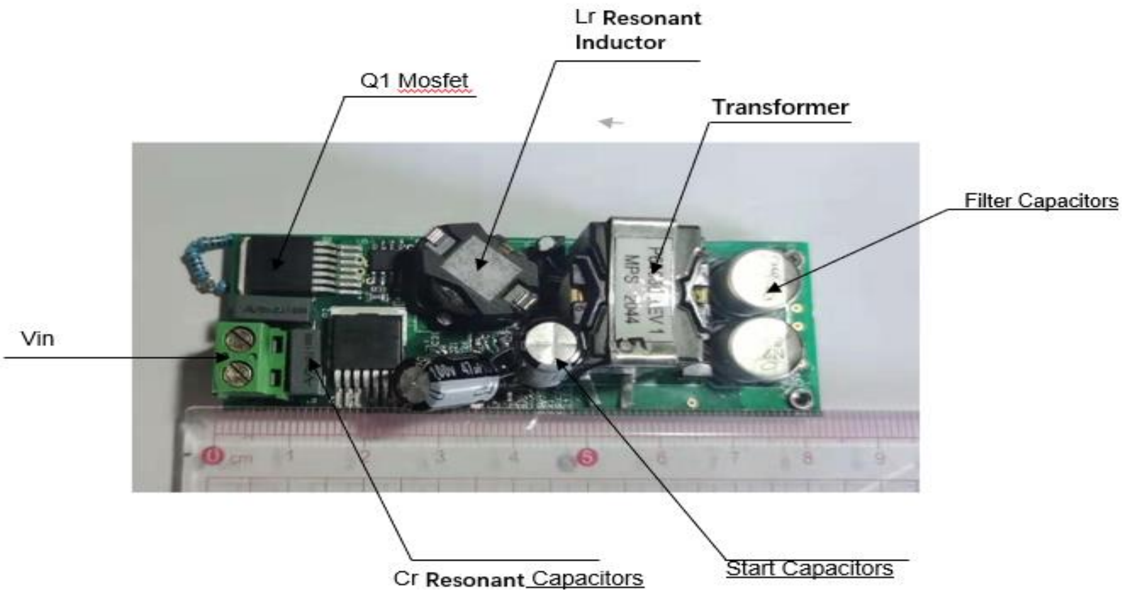


Fig. 7 Power density of discrete LLC and projected integrated LLC

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As shown in the Fig. 7, the resonant power supply designed this time has a small size and high power density. Due to the superior EMI performance of the resonant converter, it can be easily added to other power supply design projects as a general module. The key operating condition waveforms obtained from the experimental test are as follows:

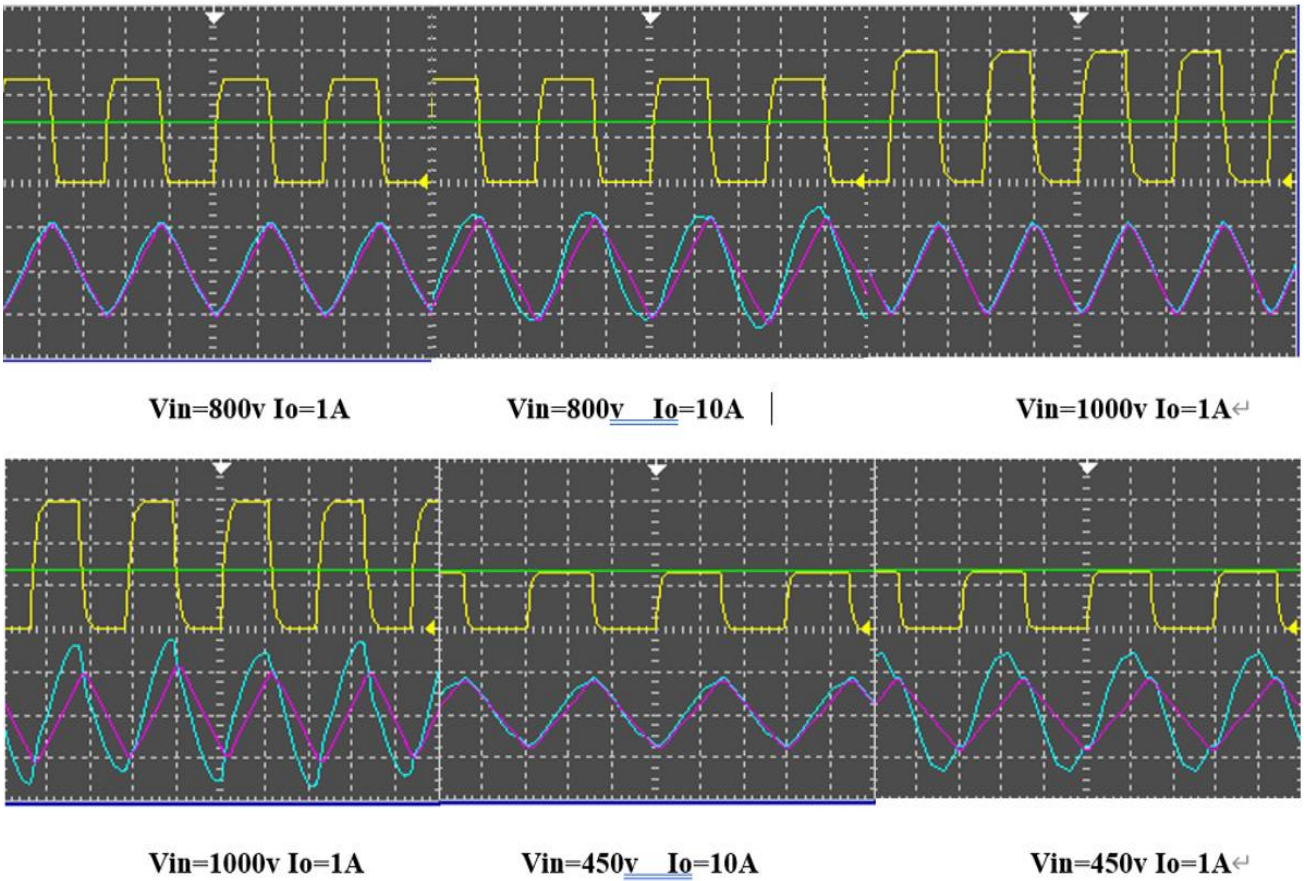

Fig. 8 Test waveform of LLC converter

Select three representative three points in the input range of 450v to 1000v to observe the experimental data.

As shown in the Fig. 8, 800v input 240w output is the rated working state of this design power supply. At this time, the power supply works at the best resonance point F0, and the circuit presents a pure resistance state with the strongest load capacity. Excellent performance under both light load and heavy load turntables. You can see that the waveform with less disturbance in the figure is representative. The power supply works in an inductive state when 1000v is input, and the output is relatively stable at this time. Especially in the heavy load state, more energy stored in the magnetizing inductance can be well transferred to the subsequent load. It is difficult to output the rated power at 450V input. It can be seen that the magnetizing inductance is not charged enough, and there is a danger of entering a capacitive state. This is also one of the general directions for future improvement.

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