DESIGN AND IMPLEMENTATION THE LLC RESONANT TRANSFORMER*

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Abstract

The energy and dc to dc conversion voltage waveform of the LLC resonant transformer are required to achieve optimal working condition of the resonant region frequency. To meet this requirement, a reliable and precise instrument is needed to scan the resonant cure of the LLC resonant transformer such that its output power performance can meet the required specification.

In this paper, the design and model of a new LLC resonant transformer deployed in NSRRC is described. This LLC resonant transformer is capable of delivering energy conversion with high efficiency performance, which is better than traditional transformer, and the voltage transfer ratio is depended on the resonant Frequency. Using the simulation circuit model to develop a power converter of it is also included in the design of this new LLC resonant transformer. It has been tested and proven to be working well in power conversion with excellent efficiency and performance.

INTRODUCTION

The plan developed in our research is hoping to improve the power bus of the new power convert it changes the way of conversion energy in the power supplies with traditional 60Hz current transformer to the switching mode ones using the LLC resonant transformer. This is a technique that converts the AC line source to the setting voltage as we expect, also analyses, and applies the characteristic of the LLC resonant transformer. Various kinds of characters of the LLC resonant transformer are needed to understand in this study. For example, we need to calculate the resonant curve of its circuit model with different behavior analysis to the entity, and then design the convert circuit of the LLC resonant transformer. It somewhat differs from the common study of the hard switching transformer, so all the essentials are considered in detailed discussion in this paper.[1~3]

In order to improve the efficiency in this research, we have utilized a novel equipment to measure the resonant frequency and response curve of the LLC resonant transformer in frequency spectrum domain and calculate its equivalent circuit model and coefficient. According to the data mentioned above, we can smoothly design the switching mode PWM convert circuit. In this way, it can make the whole conversion efficiency significantly increase; however, these working frequency range are the resonant curve of this paper.[4~5]

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TRANSFORMER STRUCTURE

According to the physical characteristic of the LLC resonant transformer, we make the prototype of LLC resonant transformer, and its fundamental structure shows as figure 1. Its step down ratio is about 5:1 and frequency band is from 100 kHz to 120 kHz, via design and test. In this suitable resonant region, it can produce the isolated energy power.

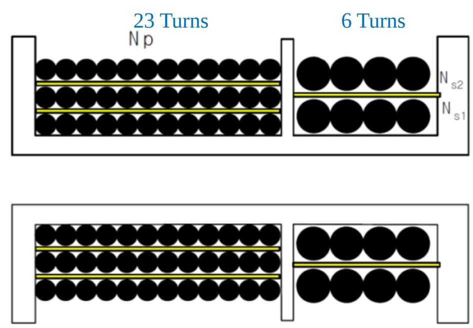

Figure 1: Fundamental structure of LLC resonant transformer.

Due to reduce the transformer temperature, we can series connection with a chock for store energy. Thus, we can list the transformer and chock specification in the table1.

Table1: The Specification of Transformer and Chock

Name	Primary	Secondary	Ferrite
Transformer	23T 0.1 $\phi\times$100	3-3T 0.1 ϕ $\times$200	7500 gauss
chock	32T 0.1 $\phi\times$100	2T 0.2 ϕ	2500 gauss

The precision of the input frequency band is quite important, especially in measuring the resonant reactions of the LLC resonant transformer. Reading from the reports and papers: the Qm value of LLC resonant transformer is very high, but resonant region is setting form Lr and Cr. From the experiment, we understand the frequency response range being about 100 kHz to 120 kHz, and this is fairly different from traditional transformers. From the figure 2, it can also verify that the energy is unable to produce any conversion if the non-resonant frequency excites the input of this transformer. Therefore, we can regard it as a band pass transformer. For that reason, it is more complicated to design the convert circuit; nevertheless we can control the output power quality and noises.

And there is no output power when frequency is out of the resonate band. This is another important advantage of using the LLC resonant transformer.

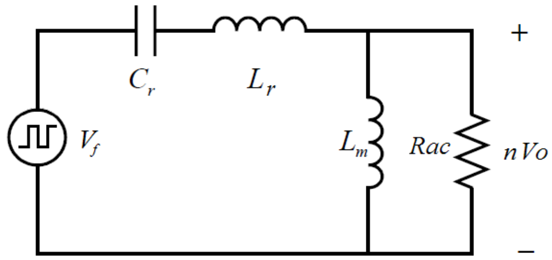

Figure 2: The structure of the LLC resonant band pass transformer.

MEASUREMENT EQUIPMENT

Viewing from the systematic research to analyze and measure the LLC resonant transformer, the essential equipment as table 1.

Table 2: The Essential Equipment for Design LLC Resonant Transformer

No.	Equipment Name	Type
1	Signal Generator	NF WF 1946A
2	Power Amplifier	NF HAS 4052
3	Oscilloscope	Tektronix TPS 2024
4	Impedance Analyzer	Agilent 4294A

Agilent 4294A is an instrument measuring impedance relative to the change of frequency of the LLC resonant transformer. It can make us find the impedance changing value in the frequency range we established. What we will look for is the minimum of impedance value Z produced by the LLC resonant transformer, and it is also the maximum value of Y=1/Z. That is the resonant frequency of the LLC resonant transformer and the optimal curve of efficiency to produce energy.

After finding out the resonant frequency from the scan frequency by impedance analyzer, we can set the resonant frequency to the signal generator. Under the operating mode, specific energy waveform produced by power amplifier delivers to the primary connection of the LLC resonant transformer. From the oscilloscope, we can observe the waveform and amplitude of the primary and secondary behavior for the LLC resonant transformer. Certainly, the resonant frequency may drift a little, because high-energy excitation results in non-linear mode for the LLC resonant transformer. Another situation, it's the influence produced by the load effect. These are what we should look for while measuring.[6]

EQUIVALENT CIRCUIT MODEL

We use Agilent 4294A impedance analyzer to get the parameter of the equivalent circuit model. At first, we short the secondary characteristic, and then sketch the diagram of scan frequency versus impedance response of the primary characteristic for the LLC resonant transformer. We can find out the maximum value for Y =1 / Z, which is the resonant stop point, as figure 3 shows.

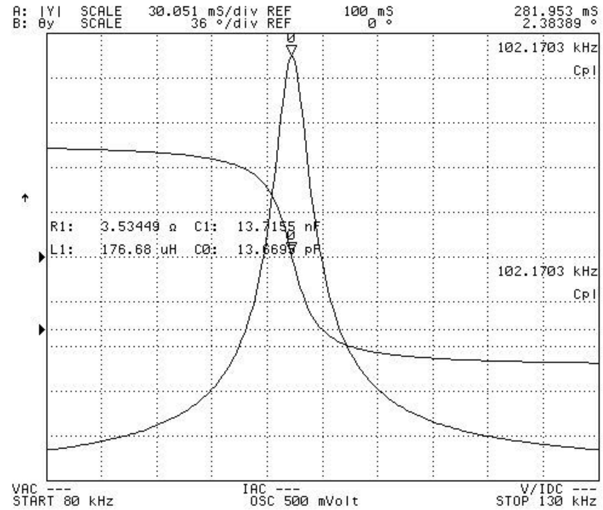

Figure 3: The diagram of scan frequency versus impedance response of the primary characteristic for the LLC resonant transformer.

The main resonant point is from the position of 100 kHz to 120 kHz. The equivalent resonant circuit model is the most appropriate selection, which accords with Type E of the Agilent 4294A LCR simulation model, as figure 4 shows. The equivalent resonant circuit model is the most appropriate selection, which accords with Type E of the Agilent 4294A LCR simulation model, as figure 4 shows.

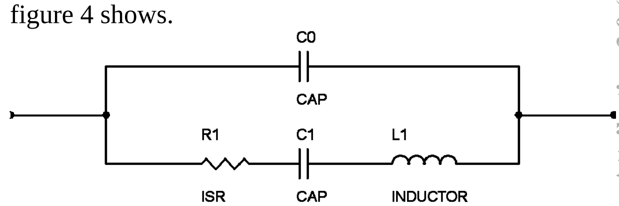

Figure 4: Type E of the Agilent 4294A LCR simulation model.

We calculate the parameter of the model via Agilent 4294A. At the same resonant frequency curve, calculate out Y curve and draw their simulation frequency response, the results show as figure 2 and in the table 3.

Table 3: The Measured Parameters Result of the Model E and Resonant Frequency at 100 kHz

Name	R_{1P}	C_{1P}	L_{1P}	C_{0P}
Value	3.5ohm	13.7nF	176.7uH	13.7pF

Among them, the resistance R_{1P} in series is the internal resistance of the primary behavior for the resonant transformer. We can get 1000W output of the supply bus, if we use the current about 2.5 amperes to pass the primary connection, it will produce the thermal energy above 21.875W.

We short the primary connection to observe, calculate and simulate parameters of the secondary connection for the transformer, as figure 5 shows, using the Agilent 4294A impedance analyzer. Namely, it is the relation diagram of the resonant curve versus frequency of the secondary connection. We can get the coefficient from these measurement and calculation as table 4.

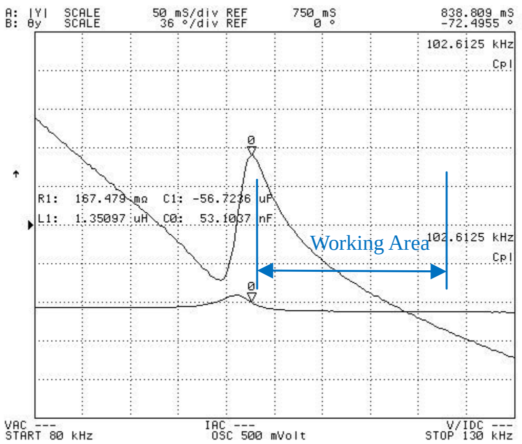

Figure 5: Impendence response diagram of the secondary characteristic for the resonant transformer.

Table 4: The Measured Parameters Result of the Secondary Parameters

Name	R_{1S}	C_{1S}	L_{1S}	C_{0S}
Value	0.17ohm	56.7nF	1.36uH	53.1pF

We can get 1kW and 50V output of the supply bus, if we use the current about 10 amperes to pass the secondary two rectifiers connection, it will produce the thermal energy above 34W. So we can get the core loss and conduction loss, which is total loss of the transformer, is 55.875W and equal to 5.6%. The transformer's loss is very small. It's close to the resonant frequency from the experiment tested at the beginning using the power amplifier. It proves that the power bus of the above experimental methods.

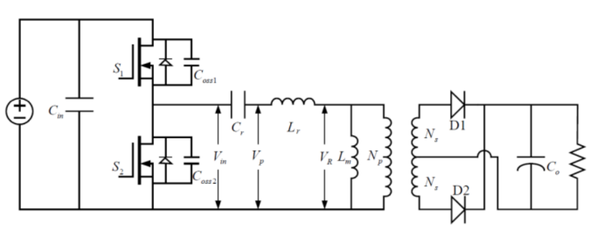

Figure 6: Resonant half bridge topology.

RESONANT CONVERT

The L6599 resonant PWM Controller is the core controller of the switching control circuit. It is an adjustable frequency of switching controller. We apply it to implement the PWM controller circuit of the resonant transformer, which regulates the output voltage. Because this resonant transformer works around 100 kHz to 120 kHz of resonant frequency, and its power stage needs to implement from half bridge topology as Figure 6.[7]

CONCLUSION

The essential methods in this research are resonant region scanned and equivalent circuit model construction of the resonant transformer. By the measurement quantities through the Agilent 4294A and calculating its equivalent circuit model, we can choose resonant frequency while designing the resonant switching PWM dc power bus.

Our study purpose is the development of resonant power supply and their control circuits producing the power bus. It provides the 50V dc power bus to MCOR30 correction power supply to solve the problems such as volume miniaturization, low weight, 90 to 240V universal ac input voltage with power factor control, independent power bus and efficient enhancement. On the other hand, there is an inevitable problem that it produces much more noises. The high quality and low current ripple are desperately required to the correction power supply in the NSRRC. In this way, we should be prudent to develop this technology.

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