Design and Optimization of Inductive Wireless Power Transmission System

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Abstract: The inductive wireless power transmission system is actually applied to the principle of magnetic field coupling, combined with the flexibility of the electrical equipment to achieve flexible and safe power supply. In the realization process of wireless power transmission, the key point lies in the transmission efficiency and power transmission capability. However, wireless transmission still has some disadvantages in these two aspects. In this case, there is an air gap between the transmitting winding and the receiving winding. If it is too large and the coupling coefficient is too low, in view of this situation, it is necessary to carry out research from aspects such as raising the coupling coefficient and controlling the air gap. The article firstly describes the development ofwireless power transmission technology and transmission principles, etc. Secondly, it analyzes the output control ofwireless power transmission systems. Third, it conducts simulation analysis using loosely coupling transformers and proposes an optimized solution. The simulation design and inspection process were proposed. The main purpose of this paper is to analyze the current wireless energy transmission system and clarify the direction in which it should be strengthened. The significance of this study is to provide a feasible direction for the further optimization of the wireless energy transmission system.

Keywords: Inductive; Wireless power transmission system; Optimization

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1. Introduction

The research on the optimization of magnetic coupling mechanism presents a lot of research data, and its direction mainly focuses on the influence of different magnetic core structures on the coupling coefficient, the influence of different number and shape of radial magnetic stripes on the coupling coefficient, and so on. In this study, the finite element analysis software of electromagnetic field was simulated and analyzed under different conditions and the analysis results were taken as the basis to propose the optimization scheme of the wireless power transmission system.

2. Overviewon Wireless Power Transmission

2.1 Development of Wireless Power Transmission

The so-called wireless power transmission is to realize the transmission of electric energy under the condition that no contact is needed, and the realization process thereof is to convert electric energy into other forms of relay energy by means of a transmitter, after performing a length of space transmission, by means of receiving The device converts it into electrical energy and achieves wireless transmission in the middle segment.[1] The first test of wireless power transmission occurred in 1890. It was originally conceived to regard the Earth as an inner conductor and the Earth's ionosphere as an outer conductor. After amplifying the transmitter, an electromagnetic wave oscillation mode was implemented and electromagnetic waves around the surface of the Earth were applied. The transmission of energy, but due to the technology required for this concept and the lack of funds, ultimately failed to complete the test. The idea of electromagnetically coupled inductive wireless power transmission emerged in the late 20th century. This is also an important node in the development of wireless power transmission. Research on this direction has been carried out successively, and more and more relevant information has provided important foundations for the development of this technology. As far as the domestic aspect is concerned, the research time for this technology is relatively short, and the initial research appeared after the year of 2000. However,overall speaking, the development of domestic wireless power transmission technology is relatively fast.

2.2 The Transmission Principle of Wireless Power Transmission

The principle of wireless power transmission can be subdivided into three aspects: First, the application of the principle of electromagnetic induction. Specifically, it is applied to the principle of electromagnetic induction in non-contact mode charging technology. This technology is more common in the field of portable terminals. Under this principle, two coils are placed at close distances, and the magnetic flux formed by the current passing through one coil can become a kind of transmission medium, promoting the formation of the electromotive force in the second coil.[2] with regard to the application of this transmission principle, a large number of research results have shown that the higher the original frequency of the current, the smaller the distance between the secondary side, the greater the relative magnetic permeability of the magnetic core near the medium, the more efficient the transmission efficiency of the lift-off transformer can be. If the distance of the original secondary side is smaller during actual application, the original secondary side needs to be compensated accordingly. Second, the principle of transmitting and receiving electromagnetic wave energy through the antenna, the microwave transmission energy is actually the positioning and emission after the microwave is focused, and the microwave energy received at the receiving end is converted into direct current power via a rectifying antenna. Third, with the resonant method of electromagnetic fields, resonance technology is more commonly used in the electronic field, and only the electric field and magnetic field are applied in the power supply technology.

2.3 Research Directions of Wireless Power Transmission

As far as China's demand for electric energy is concerned, resources in the eastern and western regions are extremely uneven, and some mountainous regions or islands are far away from the large power grid and have a poor power supply environment.[3] Under these conditions, the application of microwave transmission technology can effectively improve the situation of power consumption difficulties, and transmission engineering is more concerned with transmission efficiency and economics. The transmission efficiency of wireless power is mainly affected by the microwave source efficiency and the emission efficiency, and the economy is affected by the price of the microwave component of the applied frequency band and the price of the related equipment. In addition to the above two research directions of transmission efficiency and economic efficiency, the issue of the impact of high-power microwaves on the environment and human health is also a relatively concerned direction. The research results presented include the following aspects: first, there is no obvious correlation between the density of transmitted microwave energy and ionospheric disturbance; second, the impact on daily communications must be controlled during the application of wireless power; and third, the ground-based rectifying receiving station must not make a negative impact on aircraft and other vehicles.[4]

3. Analysis of Output Control of Wireless Power Transmission System

3.1 Based on DC(Direct Current)-DC Conversion Output Control

The DC-DC conversion output control is to add a DC-DC change link to the original or secondary side of the WPT (Wireless Power Transmission) system to realize the control of the output. The process is shown in Fig.1. By adjusting the bus voltage of the high-frequency inverter on the primary side DC-DC converter, the linear adjustment of the output voltage of the WPT system is induced.[5] The secondary DC-DC conversion control regulates the output voltage current by adding a regulated voltage control device to a section of the wireless power transmission system. Under normal conditions, adding a DC-DC link to the primary side can give a linear adjustment to the output voltage. If a DC-DC conversion link is added to the secondary side, it will affect the equivalent load resistance, resulting in a wireless energy transmission system. The development of non-linearity towards the direction of complications, in response to this situation, during the application, DC-DC links will be added to the primary side. The DC-DC output control method belongs to the double closed-loop WPT system control form. Combining with the detection signal of the output voltage of the WPT system, the DC-DC output voltage is adjusted to indirectly control the output closed loop of the WPT system.[6] At the same time, wireless communication has certain delay characteristics, and its transmission quality will be reduced in extreme electromagnetic environment. Therefore, in the control process of the entire system, the current closed loop needs to be effectively controlled. From the analysis of the DC-DC conversion output control technology, there are obvious advantages in adjusting the power range, adjusting the reliability, etc. However, such a control scheme increases the primary power conversion, resulting in a reduction in the overall efficiency of the system. This led to an increase in overall input costs.

3.2 Based on High Frequency Inverter Constant Frequency Control

With regard to the limitations of DC-DC converters in the application process, related research results in recent years have shown that high-frequency inverter control solutions have a relatively good effect. There are numerous inverter control schemes. Based on the constant frequency problem, they can be subdivided into two types: constant frequency control and variable frequency control. Inverter constant frequency control can be subdivided into multi-

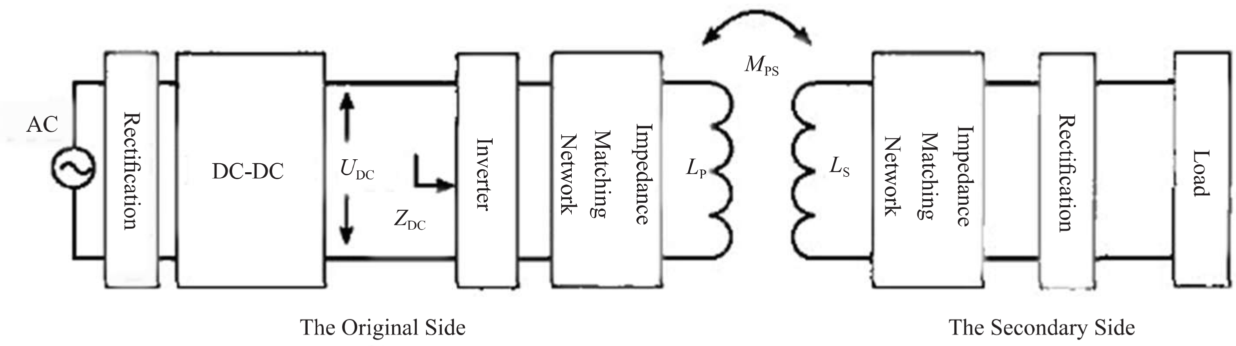


Figure 1. DC-DC Conversion Output Control Chart

ple forms, but the method used in high-frequency controllers is mainly PWM (Pulse-Width Modulation) controlled phase-shift control. SPWM and SVPWM (Space Vector-Pulse-Width Modulation) are mostly used in low-frequency inverters.[7] The S-S type control method is a wireless power transmission system based on the ICPT. As shown in Fig.2, the voltage type inverter to be applied applies capacitive series resonance compensation to the primary and secondary sides. In the application process of the PWM control mode, the driving pulse of the switch tube is as shown in Fig.3, and the driving waveforms of the two switch tubes in the position of the angle line are the same. At the same time, the space ratio of the four switch tubes is also the same. The disadvantage of this method is that the four switch tubes at t2 and t4 are all turned off. Under this condition, the integrity of the current path of the primary coil is lost, and a certain amount of electromagnetic interference will be formed, whilethe smaller the space occupied by the PWM is, the more obvious the interference will be.[8]

By controlling the output power of the wireless power transmission system via the phase-shift control scheme, unnecessary hardware circuits can be reduced. When the load is constant, the output power can be adjusted by applying the phase-shifting method. If there is a change in the load, if there are multiple for the secondary side receiving coils, the phase wise control strategy should be selected to give control over the entire system output.

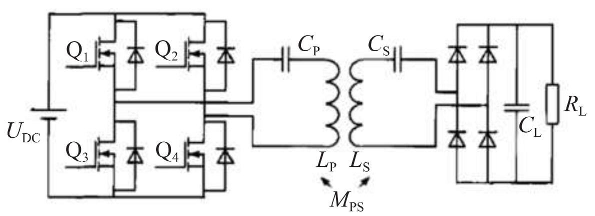


Figure 2. S-S Type wireless powerTransmission System Structure

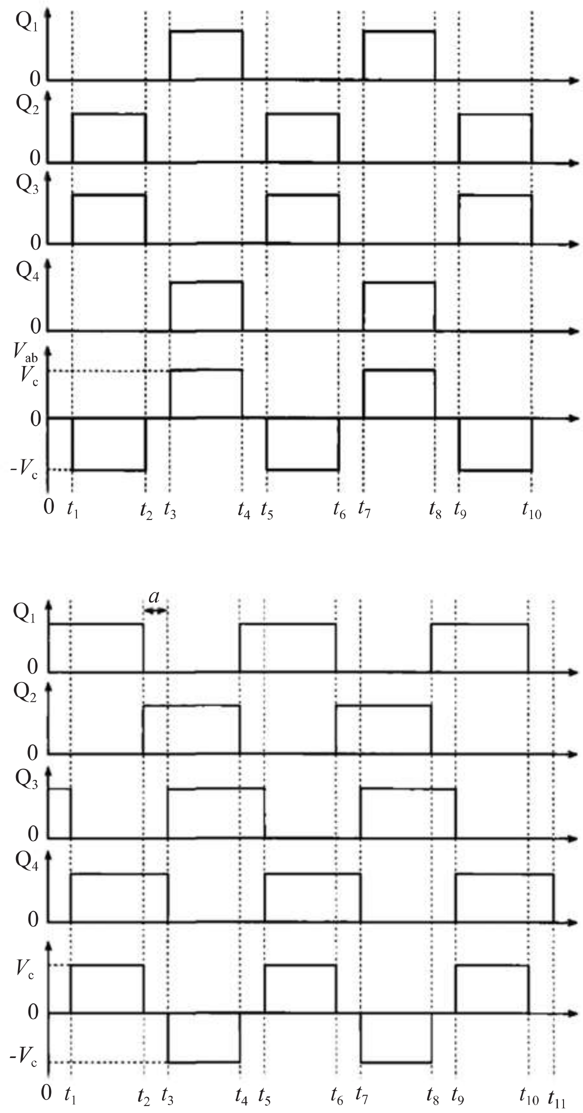


Figure 3. PWM ＆ Phase Shift Output Control Method Comparison Chart

3.3 Based on High Frequency Inverter Pulse Frequency Modulation(PFM) Control

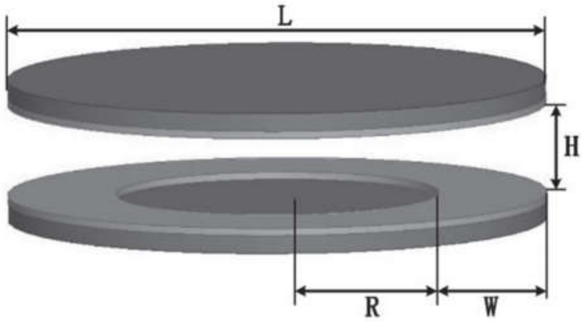
There is a certain correlation between the transmission power and the operating frequency(f)of the WPT system. If the operating frequency of the inverter is adjusted, the corresponding system power and transmission efficiency will also change. If the system transmission efficiency is relatively high, Stability, and the system output road in the system frequency changes, you need to choose PFM control technology to control the output of the system.[9] In the process of formulating the FM control scheme, the frequency of the wireless power transmission system should be combined with the frequency characteristics to determine the best operating frequency range. If the system is under-coupled, critically coupled, out-of-coupled,output power adjustments can be made in both operating frequency ranges. If the system is over the coupled state, there will be two maximum transmission frequencies with the specific performance that there are two peaks in the output power, but the system transmission efficiency won't change significantly. The control operation of PFM is relatively simple and has high reliability. However, for a fixed system, the nonlinearity of output power control via frequency adjustment is more obvious. If the frequency modulation range is too large, the stability of the system will be affected. Therefore, this adjustment scheme is more suitable for use in systems with a smaller frequency range.

4. Loosely Coupling Transformer Simulation Analysis and Optimization

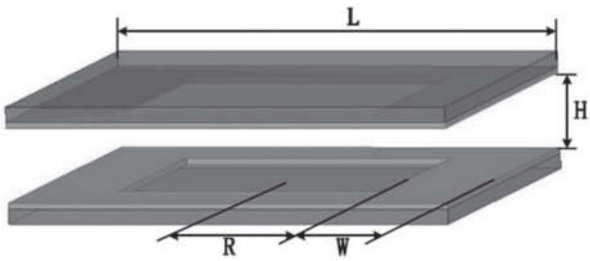
The coupling coefficient of the loosely coupling transformer plays an important role in the transmission performance of the system power. It is necessary to obtain the maximum coupling coefficient under the relevant standards in the design process of the power higher density loosely coupling transformer.

4.1 Magnetic Core and Coil Structure Analysis

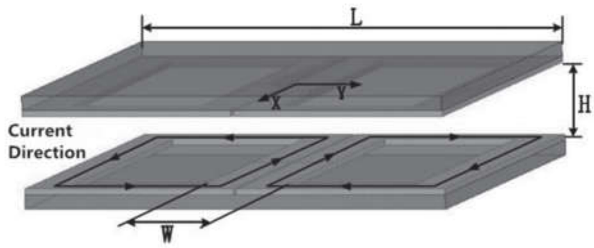
As shown in Fig.4, the different types of planar loosely coupling transformers are compared. The three types of cores are PC95 ferrite cores with a thickness of 10cm, but the coils have some differences, including round Shape, square, DD-shaped winding, transformer parameters are set to: magnetic core size L = 300mm; coil diameter R = 90mm; coil width W = 60mm. In order to control the influencing factors of the comparison result, the three groups of primary and secondary sides are set to be the same. If the vertical distance between the transmitter and the receiver changes or if there is a deviation in the horizontal direction, the magnetic field distribution will change, which will affect the degree of coupling. As shown in Fig.5, in the environment where there is no horizontal deviation between the primary side and the secondary side, the coupling coefficient will change under the change of the vertical distance, that is, there is a linear relationship between the coupling coefficient and the air gap. The coupling coefficient decreases as the air gap increases. In its uniform space environment, the coupling coefficient of the square-structure loosely coupling transformer is the highest.



(a) Round-Shaped Loosely Coupling Transformer Structure



(b) Square-Shaped Loosely Coupling Transformer Structure



(c) DD-Shaped Loosely Coupling Transformer Structure

Figure 4. Plane Type Loosely Coupled Transformer Structure

4.2 Analysis of Influences of Coil Winding Positions on Coupling Coefficient

The selected core is a square core with a size of 300mm x 300mm and a coil width of 60mm. The relative position of the coil and the core will cause a certain influence on the coupling of the primary and secondary sides. As shown in Fig.6, the coupling coefficient is within the coil inner diameter. When there is a change, it will change accordingly. It can be understood that the coupling coefficient will increase continuously as the inner diameter of the coil decreases. The reason for this is that the total magnetic field of the coil with a larger inner diameter will be larger. If the inner diameter of the coil is 80 mm, the corresponding coupling coefficient will also be in a peak state and then gradually decrease.From the analysis of the change of the magnetic field induction strength, under the condition that the outer diameter of the coil is close to the outer diameter of the core, both the original and secondary coil will obtain the highest magnetic field induction intensity under the same current excitation, and the corresponding coupling effect will be better.

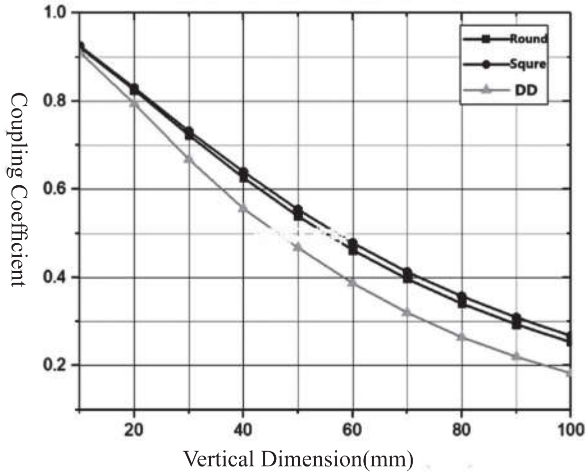


Figure 5. Vertical Dimension and Coupling Coefficient Diagram

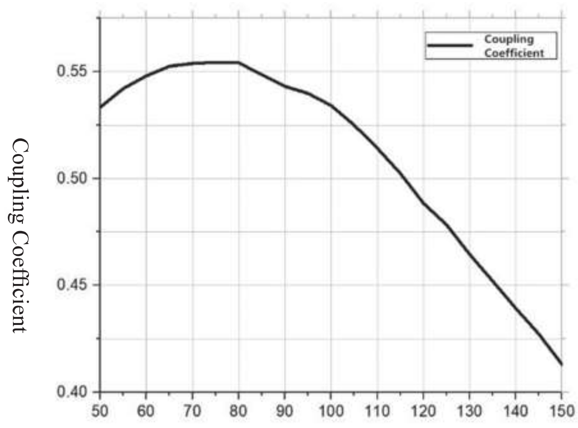


Figure 6. Coil Inner Diameter and Coupling Coefficient Diagram

4.3 Magnetic Core Structure Optimization Design

The main value of the planar magnetic core is to provide magnetic paths for the alternating magnetic field formed by the high-frequency current in the coil. Combined with the above analysis of the core structure and the correlation of the coupling degree, it is implemented without affecting the coupling coefficient. Optimization measures help to reduce the volumetric quality of the transformer. Select the brand new loosely coupled transformer as shown in Fig.7. The optimization of this type of transformer is based on the original square core. No adjustment is made to the inner diameter of the coil. The adjustment is made by changing the original core. For the magnetic stripe, in order to ensure that the magnetic stripe does not become saturated based on too thin, the magnetic core magnetic induction intensity in the simulation result is observed. The observation result is shown in Fig.8, when the original secondary coil is excited by the current of 20 A, The proximity magnetic field of the coil is about 25mT.

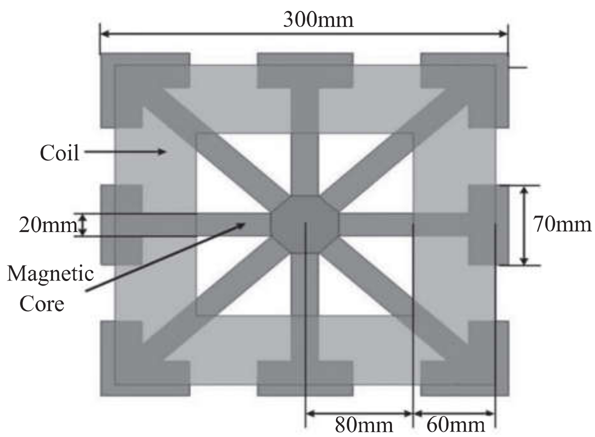


Figure 7. The New loosely Coupling Transformer Structure

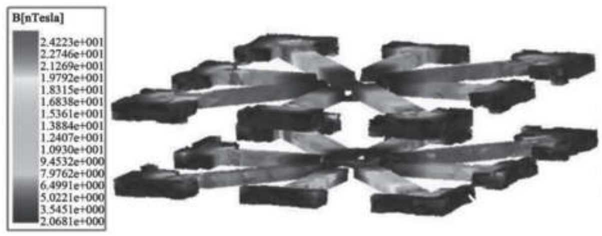


Figure 8. Magnetic Core's Magnetic Induction Intensity Distribution Diagram

5. Simulation Design and Inspection

Through the joint finite element analysis of Maxwell electromagnetic field and Simplore circuit system analysis, an accurate wireless power transmission system simulation model can be obtained. In combination with the above reactive power compensation network for the new loosely coupled transformer, the bilateral LCC compensation topology is selected. The interface is shown in Figure 9. The power Vin is an analog inverter output square wave voltage source, Lf1, Cf1, C1 constitute the primary side resonant compensation network, Lf2, Cf2, C2 constitute the secondary side resonant compensation network, the parameters via the resonant frequency, the primary and secondary side of the transformer Sense of clarity. After operation, the primary side resonant network input voltage and current waveforms can be obtained. As shown in Fig.10, the air gap between the original and secondary sidesof the loosely coupling transformer is 50mm. There is no horizontal input offset simulation input waveform. In this stage, the input voltage and input current with the same phase, the system operates at unity power factor. After adjusting the position of the primary and secondary coils of the loosely coupled transformer, the coupling coefficient changes, and the system still operates at the unit power factor, which meets the design standards.

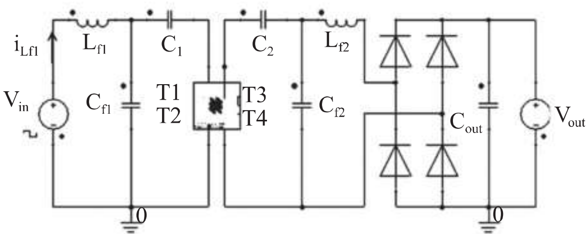


Figure 9. Co-Simulation Circuit Diagram

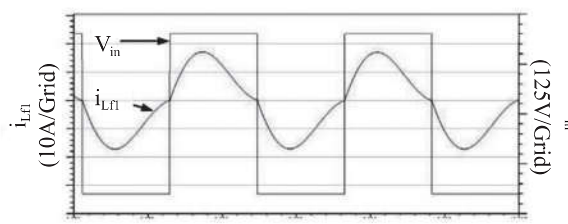


Figure 10. Primary Resonant Network Input Simulation Waveform

6. Experimental Verification

To verify the entire simulation result, an experimental platform is constructed as shown in Fig.11. The input of the inverter is connected to a 400V DC power supply, the primary compensation network, the loosely coupled transformer, the secondary compensation network, and the rectifier is connected to the load. The parameters are the same as those of the simulation circuit. As shown in Fig.12, the input voltage of the system is 400V, and the primary side air gap of the loosely coupled transformer is 50mm. There is no input waveform of the primary resonant network under the horizontal offset condition. What can be learned is that the experiment waveform and the simulation waveform are the same. Under this condition, the system work is under the unit power factor, the output power is 3.3KW, the actual measurement efficiency of the whole system is higher than 95%, and this kind of wireless power transmission system can be confirmed, which meets the design criteria.

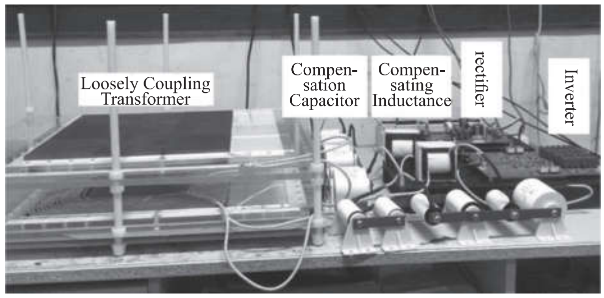


Figure 11. Experimental Platform Structure

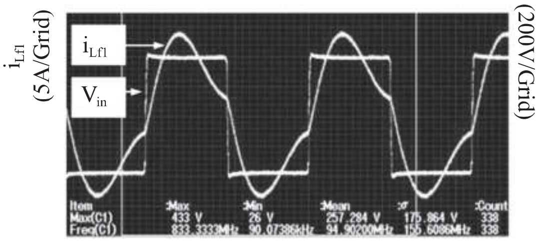


Figure 12. Primary Resonant Input Waveform

7. Conclusion

Application advantages of inductive wireless power transmission technology embodied in the enhanced flexibility of the power equipment, but also help to improve the security and flexibility of power supply. But in the realization of wireless power transmission project it is also facing some problems, including transmission efficiency and transmission functions, etc., which are expected to be improved. From the results of the comparative analysis of loosely coupling transformers of different types in the article, the magnetic core was reformed and optimized on the basis of the original square loose-coupling transformer, and a new high-power loosely coupling transformer was designed under the restrictions of the relevant standards and combined with simulation verification which confirms that this optimal design meets the standards.

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