Analysis of Fixed-Frequency Voltage Regulating and Fixed-Frequency Duty Cycle in Magnetic Induction Wireless Charging

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Abstract. This paper summarizes the comparison of fixed frequency voltage regulating and fixed frequency duty cycle regulating in Qi Specification by using Electromagnetic Induction Power Transfer Technology.

1. Introduction
The receiving and transmission of electric energy has long been carried out by direct contact between semiconductors. With the classification and standardization of wireless power receiving and transmission technology gradually unified, meanwhile the cost of wireless power transmission and the efficiency of wireless energy transmission are approaching to the wired power transmission mode, main technical bottleneck of wireless power receiving and transmitting is gradually being broken down. With the further development and expansion of intelligent terminal market, and growing demand for battery life and charging time flexibility for smart terminals, technical requirements for "tailless" are becoming increasingly urgent. On the other hand, the transmission of electric energy in wired network has always been haunted by limitations of many interface and protocols. Therefore, wireless power receiving and transmitting technology has been paid more and more attention by the society because of its advanced transmission technology and performance, and has gained a lot of beneficial scientific experiments and technological exploration.

2. Main power receiving and transmitting mode
The technology of wireless electric energy transmission directly realizes the wireless collection and transmission of electric energy by using wireless electric field, magnetic field, microwave and laser and other wireless electric energy transmission tools and media. Wireless power transmission technology can be divided into three types according to its transmission mode, which is Wireless electromagnetic induction power transmission, Magnetic Coupling Resonant power transmission and Radio waves power transmission.

The transmission of electromagnetic induction wireless electric energy is realized by the interaction of two close electromagnetic induction coils. For example, the primary coil in the transmitter generate alternating induction magnetic field by current in the coil, the secondary coil in the receiver picks up the alternating magnetic field, so that in the electromagnetic induction coil directly induced current, the two-way transmission of wireless power from transmitter to receiver is realized. The flow chart of electromagnetic induction mode is briefly described as follows.
As shown in Figure 1, the transmitter outputs the AC power through the inverter of the transmitter rectifier to the transmitter driver, the controller of the transmitter controls the drive circuit through alternating current in the coil at the original edge of the transmitter. The Receiver obtain alternating current and magnetic field through the coil side, thus generating input and output induced current in the transmitter coil, respectively. The DC voltage required for the load are obtained by converting the current through the rectifier at the back end. The controllers at both ends monitor and automatically adjust the voltage and current state, and add the communication power and signal modulated by the transmitter to control the energy and signal transmitted by the coil, so as to realize the cooperative working control and automatic communication at both ends. In the entire working process of control and automatic communication, it is necessary to realize the system design and control driven by transmitter and controller, the system design and working control of receiver signal pickup, coil drive system design and improvement. Only the cooperative of each control part can make the power transfer to the system more efficiently, the system working stabler and securer.

The principle of magnetic coupling resonance is adopted in the magnetically resonance mode. When the magnetic field at both ends of the power transfer device varies at the identical frequency, the efficiency of energy transfer will climb up to the peak. The most different feature compared to Electromagnetic Induction Mode is that a certain space is allowed between the transmitter and receiver, no need to pursue a complete match between the relative positions between the coils.
The main characteristic of the transmission mode of magnetic coupling resonant wireless electric energy is that it consists of two parts: the transmission control device and the power receiving control device of the system. When the resonant frequency of the original side coil is the same as that of the secondary side coil, the system is in a strongly coupled energy transmission mode. The high efficiency and long distance transmission of wireless power can be realized directly by medium and high frequency magnetic field transmission, while the interaction between the system and the power receiving device deviates from the resonant transmission frequency is weak. This transmission mode enables the system to effectively bypass obstacles and realize the transmission of various long-distance wireless power, which has a wide range of market applications and prospects.

The principle of radio wave transmission technology is mainly to convert the electric energy in the atmosphere directly into a transmission mode of microwave or laser. It is widely used in ultra-long-range and close-range transmission. One of the essential principles of radio wave transmission technology is that the directional electromagnetic wave emission beam directly replaces the cable supplied by wired laser, and realizes the wireless and long distance transmission of electric energy. When the directional electromagnetic wave propagates in the atmosphere, the shorter the wavelength range, the less easy it is to disperse in the atmosphere, so we can directly realize the long distance transmission through the microwave and directional laser in the atmosphere. However, due to microwave and laser cannot effectively bypass the obstacles in the atmosphere, and because of the large number of dust and suspended particles in the atmosphere, the efficiency of long-distance propagation is greatly reduced, and the transmission power is small. In addition, microwave loss may cause some harm to biological health in polluted environment.

![Radio Wave Power Transfer Scheme](image)

The technical enterprises in the industry has formed three standardization systems of technology organization around the field of wireless charging technology, based on the two development directions of magnetic induction and magnetic resonance, which is A4WP, WPC and PMA. In 2015, the consolidation of the two standard organizations into AirFuel in A4WP and PMA has to some extent alleviated the confusion of standards. Specifically, Qi specification is the most widely used wireless charging specification worldwide among this two groups. A comparative analysis of constant-frequency voltage regulation and constant-frequency duty cycle in magnetic induction wireless charging based on Qi specification is presented in this paper.
3. Wireless fixed-frequency voltage regulating and fixed-frequency duty cycle regulating based on Qi spec

Qi specification definition framework is suitable for small electronic equipment, which has flexible charging position, supports transmitter design for single coil receiving equipment and multi-coil receiving equipment application, and simple communication interface protocol and low standby power consumption. The specification specifies and recommends the fixed frequency transmitter, receiver, system communication, control mode, algorithm and related structure respectively.

3.1. (a) The Fixed frequency transmitter

Mainly composed of Control module, full bridge rectifier module (generally composed of four MOS tubes), voltage regulation module and other modules. The control module controls the logic state of the whole circuit, the full bridge rectifier module is a DC conversion transaction current, the voltage regulating module adjusts the output voltage. Other modules include decoding and necessary input and output functions, which will not discuss in this paper.

3.2. (b) Receiver

Mainly composed of full bridge rectifier module, control module and other modules, the full bridge rectifier module is used to convert AC to DC. When the voltage is high, the half bridge is selected to work, and when the voltage is low, the full bridge is put into work. Besides, the control module is used to control the logic state of the whole circuit. The other modules modulation and necessary input and output. Commonly, Receivers are generally fully integrated SOC, that is, a single chip with some resistance capacitance.

3.3. (c) Voltage regulation mechanism

The transmitter can adjust the energy by adjusting the working frequency of the rectifier module, or by adjusting the pulse width of the working frequency of the rectifier module, as well as adjusting the direction of the working frequency of the rectifier module. The energy can be adjusted by the working voltage of the rectifier module.

3.4. (d) Fixed-frequency Voltage Regulating

Fixed frequency voltage regulation, as the name implies, is regulating voltage by fixed frequency. The fixed frequency recording here is the fixed frequency of the full bridge rectifier module, and the output voltage of the voltage regulating module is adjusted.

3.5. (e) Fixed-frequency duty cycle Regulating

The fixed-frequency duty cycle regulating, that is, fixed frequency, adjusts the voltage by adjusting the pulse width of the working frequency of the rectifier module, and the pulse width is the duty cycle. So fixed-frequency voltage regulation has voltage regulation circuit, fixed frequency duty cycle has no voltage regulation circuit. That is, for the circuit with fixed-frequency voltage regulation, the voltage
used in the rectifier module is the output voltage of the voltage regulation circuit, and the voltage used in the rectifier module with fixed-frequency duty cycle can be understood as the input power supply voltage, so the rectifier voltage is different. This is the difference in circuit structure.

4. Comparison between Fixed-frequency Voltage Regulating and Fixed-frequency duty cycle Regulating

4.1. (a) Output capacity factor
From the output energy point of view: fixed-frequency voltage regulation needs to have a voltage regulation module, generally a voltage reduction module, so compared with the fixed-frequency duty cycle, the maximum energy output by fixed-frequency voltage regulation is less than that output by fixed-frequency duty cycle mode for the same power input voltage. However, the maximum energy requirement of the receiver is much smaller than the maximum energy output of the transmitter, which is the difference of the maximum output energy.

4.2. (b) Work mode factors
Both Fixed frequency voltage regulating and fixed-frequency duty cycle regulating are aim at the 7.5W charging level of iPhone, so the transmitter must reach at least 10W of output capacity, that is, the input voltage must be at least 5V, and the current mainstream transmitter spec is 9V rated voltage. Because the voltage of the rectifier module is adjustable, the rectifier module regulation mode can use a "proper" input voltage to Ping, and obtain the constant output energy with 50% complementary duty cycle (not considered in the dead zone). On the contrary, the fixed-frequency duty cycle adopts another method. When the 5V input voltage is used to Ping, the input energy is obviously too small to meet the demand of 7.5 W, so when the fixed-frequency duty cycle transmitter encounters 7.5W iPhone, 9V input power will be selected. 9V power supply works with 50% complementary duty cycle, the energy is too large to meet the requirements. So the transmitter chooses to reduce the energy of the Ping by adjusting the pulse width, or duty cycle. If the power is too high, the receiver may be damaged, so the energy is reduced by adjusting the pulse width, which is a difference in working patterns.

4.3. (c) Stability factors
The duty cycle of fixed-frequency modulation needs a narrow duty cycle Ping, which is generally between 5%~20%, and can be understood as "pulse type" energy with high voltage and narrow pulse width. When the pulse width is too narrow, the decoding and stability of the transmitter are affected, when the pulse width is too wide, it will affect the state of the receiver, and even damage the receiver if the sensing distance is close. For the receiver, the received "pulse" energy requires a stronger capacitor to filter it into a relatively stable direct current. When iPhone chose fixed-frequency because of interference, because the "pulse" energy is not fully compatible with the mobile phone screen or other circuits, so iPhone "approved" is the standard fixed-frequency voltage regulation mode. This is the difference in stability.
4.4. (d) Solution cost factors
Because the fixed-frequency voltage regulation mode has one voltage regulating circuit more than the fixed-frequency duty cycle mode, the cost of the fixed-frequency voltage regulation mode is a little higher than that of the fixed frequency regulation mode. At present, the market is relatively mature, the cost is 5~10% difference, as the market becomes more and more mature, we believe that the later difference in cost between the two will be smaller and smaller.

4.5. (e) Noise factors
Due to the fixed-frequency voltage regulation use the step-down circuit, which generally have inductance, so the fixed-frequency voltage regulation mode will be slightly larger than the fixed frequency duty cycle in the communication noise. However, currently the fixed-frequency voltage regulation method has become more and more mature, and there are many methods to deal with noise. Most of the fixed frequency voltage regulation products in the market are perfectly handled in noise, which can be completely satisfied with the use of various occasions.

5. Conclusion
Wireless charging products are becoming more and more popular, as many as thousands of new registered products every year. At present, in the market the domestic fixed-frequency duty cycle regulating occupied more than half. Compared with the international market, the share of fixed-frequency voltage regulation is relatively higher. It is believed that with the market gradually mature, competitive, quality assurance products will be more and more cost-effective, nonetheless, it is believed that in the near future, many more frequency regulation methods will appealing, and will be more and more recognized by the user experience.

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