Power Control of Wireless Power Supply System Based on Fuzzy PID Control

Abstract: Wireless power supply technology because of non-contact power supply mode, has a good application prospect in the industry of instruments and meters. But in terms of mine electric locomotive adopted wireless power supply technology, loading condition changes and relative movement on power supply rail of mine electric locomotive will change the load and the coupling parameters of wireless power supply system. These changes of these two parameters will have great influence on the output power of the wireless power supply system. The above problems must be properly controlled so as to ensure the stability of the output power. Because the system contains a large number of non-linear elements, traditional quantitative analysis is too complex; and when the system encounters unexpected situations, the robustness of traditional control technique is poor. Therefore, the fuzzy PID controller is proposed to control the power output. Through validated, this program has stronger robustness and it can be applied in the wireless power supply system very well.

Keywords: fuzzy PID control, wireless power supply, robustness, instruments and meters

1 Introduction

Electrical equipment requires a stable input in order to ensure safe, stable, long-term operation [1]. To stabilize the output of system power, it is necessary to take corresponding control measures to ensure the stability of the output power. Output power and the transmission efficiency of wireless power supply system have close relation with the coupling coefficient and its load. However, these two parameters can be changed easily [2]. If the charging device moves, it will result in changes of coupling parameters [3]. This paper adopts the non-isolated DC-DC control technique, because it is suitable for high power wireless power supply system and it
does not have the transformer usually used in isolated control technique that will increase the system loss and volume [4]. To simplify the structure of system, the process of energy conversion and pressure transform, it employs BUCK-BOOST circuit because of the bigger range of output voltage and the post circuit protection utilized with the switch transistor. In order to stabilize output power. This paper uses the fuzzy PID controller to adjust the duty factor of BUCK-BOOST circuit [5]. Because the system contains a large number of non-linear components, the system presents a very complicated non-linear dynamic behavior [6]. The traditional PID controller is difficult to realize the rapid response of the system output, and the control of the overshoot amount is not very sufficient [7]. Fuzzy PID control provides an efficient way for obtaining approximate and imprecise characteristics. When the traditional quantitative analysis is too complex or the input signal may only can described qualitatively and probably, fuzzy PID control technique is very effective for dealing with this problem [8]. Finally, through proved by MATLAB simulation and physical experiment, this approach can be applied in stabilizing the output power of wireless power supply system very well.

2 Transmission of Wireless Power Supply System

When the primary and secondary coil stay in a resonant state, the system will have a high transmission efficiency. Therefore, the primary and secondary coil need access compensation capacitor circuit [8]. This paper will study the transmission characteristics of wireless power supply system based on SS type [8]. The topology of the system is shown in figure 1:

![Circuit of SS type wireless power supply system](image)

**Fig. 1:** Circuit of SS type wireless power supply system

AC rectified DC by rectifier bridge \(D_1, D_2, D_3, D_4\). Then through DC-AC inverter by inverter bridge \(S_1, S_2, S_3, S_4\), it will get the high frequency AC power. \(C_p\) and \(C_s\) are the compensation capacitors. \(R_p\) and \(R_s\) are internal resistance of the coils. \(L_p\) and \(L_s\) are
the inductance of transmitter and receiver coils. $M$ is the mutual inductance between coils. The receiver coil receives the energy. The rectifier bridge ($D_5, D_6, D_7, D_8$) rectify AC into DC. Then it will control output power by the BUCK-BOOST circuit. Simplify the circuit as shown in figure 2.

![Circuit Diagram](image)

**Fig. 2: Equivalent circuit of wireless power supply system**

U is considered as the equivalent of high frequency AC. $R_e$ is equivalent to after class resistance.

$$R_e = \frac{8}{K^2 \pi^2} R \quad (1)$$

$K$ is a ratio of the BUCK-BOOST circuit’s output and the input voltage. $R$ is the load. The circuit equations of the transmitting coil and the receiving coil are listed by the KVL law:

$$\dot{U} = \left[ R_p + j \left( \alpha L_p - \frac{1}{\alpha C_p} \right) \right] \dot{I}_p - j \omega M \dot{I}_S \quad (2)$$

$$0 = \left[ R_s + R_e + j \left( \alpha L_s - \frac{1}{\alpha C_s} \right) \right] \dot{I}_S - j \omega M \dot{I}_p \quad (3)$$

$j \omega M \dot{I}_p$ is the induced electromotive force which transmitting coil reflect on the receiving coils. $-j \omega M \dot{I}_s$ is the induced electromotive force which the receiving coils reflect on transmitting coil. The reflected impedance $Z_r$ of the receiving coil against the transmitting coil is:
\[ Z_r = \frac{-j\omega M I_p}{I_p} = \frac{-j\omega M I_p}{Z_s} = \frac{\omega^2 M^2}{Z_s} \quad (4) \]

\( Z_s \) is the total impedance of the receiving coil. When the receiving coil work in resonance:

\[ \omega L_s = \frac{1}{\omega C_s}, \quad Z_s = R_s + R_e \quad (5) \]

Through the above calculation, we can deduce the equation of the output power \( P_o \):

\[ P_o = \dot{I}_s^2 R_e = \frac{(\omega M)^2 \dot{I}_p^2}{(R_e + R_s)^2} R_e = \frac{(\omega M)^2 \dot{U}^2}{(R_e + R_s)^2} R_e = \frac{(\omega M)^2 \dot{U}^2 R_e}{(R_e(R_s + R_e) + (\omega M)^2)^2} \quad (6) \]

Keep the input voltage constant. By the above equation derived, the \( P_o \) and transmission efficiency \( \eta \) will change with the \( M \) and \( R_e \). Using MATLAB to draw when the \( R_e \) keep constant, the \( P_o \) and \( \eta \) change with the \( M \), as shown in figure 3. Using MATLAB to draw when \( M \) is keep constant, the \( P_o \) and \( \eta \) change with the \( R_e \), as shown in figure 4.

**Fig. 3:** Relation curve between \( P_o, \eta \) and \( M \)
From the above charts show, the output must be stabilized by the closed-loop control.

### 3 Impedance Simulation Results

Fuzzy PID controller compared with the traditional PID controller has less need of information, small overshoot, fast response, less error, etc., and it makes the controlled object has a good dynamic and static performance. Figure 5 for the schematic diagram:

![Diagram of Fuzzy PID control module]

**Fig. 5:** Fuzzy PID control module
This paper adopts fuzzy PID control strategies. If the output current is constant, the output power will ensure constant because of the purely resistive load. The design idea is to compare the real-time current collected in this system with the set value, and take the differences as input samples. Controller output is the duty ratio $d$ of BUCK-BOOST circuit. The constant current control of the system is realized by changing the duty ratio $d$ of switch transistor.

In the MATLAB Simulink environment, a simulation model based on fuzzy PID controller and traditional PID controller is built respectively. Simulation parameters are set by theoretical calculation. The system requires 6A output current.

Simulation steps are: set the simulation time to 0.1s, and add controller in 0.01s. When time is 0.04s, the $M$ is set from 30μH down to 20μH. When time is 0.07s, the $R$ is set from 10Ω up to 30Ω. Simulation results show in figure 6 and 7.

(a) Output current $I_o$

(b) Duty ratio $d$

Fig. 6: Waveforms of fuzzy PID control method
The simulation waveforms show that after adding the controller, we can control the duty ratios for stabilizing output of the system. But by comparison, the fuzzy PID controller simulation waveforms significantly better than traditional PID controller simulation waveforms. The systems which use fuzzy PID control system have faster response, smaller overshoot and more stable output.

4 Experimental Results

According to the theoretical calculation, a simple physical model is built to verify that the output current remains constant when the system load changes and it
proves the feasibility of using fuzzy PID control. Experiment distance between the coils is 10cm, as shown in figure 8.

![Wireless power supply device based on fuzzy PID control](image)

**Fig. 8:** Wireless power supply device based on fuzzy PID control

When the load is 10Ω, the output average voltage is 4.5V, as shown in figure 9. When the load is 30Ω, the output average voltage is 13.5V, as shown in figure 10.

![Output voltage Uo(R=10Ω)](image)

**Fig. 9:** Output voltage $U_o(R=10Ω)$
Fig. 10: Output voltage $U_o(R=10\Omega)$

Measured experiments find that when the load change, the current remain at around 0.45A, only minimal change in the test is in the range of allowable error. The experimental results show that the fuzzy PID control strategy can stabilize the output power of the wireless power supply system.

5 Conclusions

Firstly, this article analyzes the transmission characteristics of the wireless power supply system. Through the calculative equations and the charts drawing by MATLAB, the output power $P_o$ and the transmission efficiency $\eta$ will change with the mutual inductance $M$ and the load $R$. This conclusion proves that the output must be stabilized by the closed-loop control and the controller is necessary. Because the fuzzy PID controller utilized with the accurate mathematical model can get better results than the traditional control technique without relying on the system, the fuzzy PID controller which is more suitable for the wireless power supply system is adopted in this paper. Then by the illustrations of schematic diagram’s design idea and the waveforms drawn based on the fuzzy PID controller and traditional PID controller using a simulation model in the environment of MATLAB, the results show that: the simulation model which based on fuzzy PID controller has more excellent performance and better than the traditional PID controller. Finally, this paper further verifies the feasibility of the scheme under the physical model. In this paper, the research of wireless power supply system power control has a certain reference value.
References


