Research on active disturbance rejection control of wireless transmission system

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Abstract: Wireless transmission technology has attracted much attention at home and abroad in recent years. This paper studies the control of wireless transmission system to make the wireless transmission system have better control response. In this paper, the LCL type electric field coupled wireless power transfer (ECPT) system under three operation modes of open-loop, PID control and active disturbance rejection control (ADRC) is simulated and modeled, and the voltage output waveform of the system under the three operation modes without interference, white noise, pulse interference and change of its own parameters is analyzed. The voltage amplitude difference of LCL ECPT system under ADRC control is less than 50% of PID control, and the recovery speed is more than 1.2 times of PID control. When the system parameters change, the amplitude fluctuation of ADRC is only 8.2% of PID control. The ECPT system with ADRC control has better anti-interference, robustness and response speed.

1. Introduction
ECPT is a kind of wireless energy transmission mode based on high frequency electric field. Because of its special energy transfer mode (capacitance), the coupling mechanism of ECPT system has high convertibility and good electromagnetic compatibility. Through the analysis of LCL ECPT system, the equivalent circuit is obtained, and the transfer function model of the equivalent circuit is established. Under the model, closed-loop feedback is established. PID controller and active disturbance rejection controller are used to control the model.[1] Finally, by comparing the open-loop state, PID control and voltage output characteristics under ADRC, the system performance under ADRC is analyzed. The results show that the active disturbance rejection control technology adopted in this paper can make up for the weak current of traditional PID control, and improve the anti-interference ability, robustness and response ability of the system.[2]

2. LCL ECPT system and PID model establishment
ECPT system is mainly composed of six parts, namely DC source (or AC source + rectifier link), high frequency inverter link, resonance compensation link, emission pick-up electrode, rectifier link and electrical load, as shown in Figure 1.

Fig 1 schematic diagram of ECPT system
Due to the existence of LC series resonance compensation network in ECPT system, the displacement current of coupling mechanism and radiation field of compensation inductor are large. The LCL type ECPT system introduces the LCL composite resonance compensation network between the transmitting pick-up electrode and the rectifier filter link, which effectively solves the problems of displacement current and compensation inductance radiation field in the original ECPT system. The main circuit diagram of LCL ECPT system is shown in Figure 2.[3]

![Fig 2 circuit diagram of LCL ECPT system](image)

The LCL ECPT system with PID controller feedback control, when the system parameters and power load are changed, the PID controller obtains the difference between the actual voltage output and the given voltage output, and controls the on-off time of each switch tube in the inverter link, so that the system can stabilize the voltage output at the expected value through feedback regulation. The block diagram of closed loop LCL ECPT system is shown in Fig. 3.

![Fig 3 structure diagram of closed-loop LCL type compound resonance ECPT system](image)

In order to facilitate system analysis and simulation modelling, LCL ECPT system is simplified as follows under the condition of ensuring system equivalence. The equivalent circuit of LCL ECPT system is shown in Fig. 4.

![Fig 4 equivalent circuit diagram of closed-loop LCL type ECPT system](image)

The sensitivity of LCL type ECPT system parameters is high. Therefore, when selecting the parameters of system components, it is necessary to keep them within the range that can make the system work stably. In this regard, the method for selecting the parameters of each element in LCL type ECPT
system has been given in reference [9]. Thus, the parameters of each element in this paper can be obtained, as shown in Table 1.

| parameter | value | parameter | value |
|-----------|-------|-----------|-------|
| $C_1$/nF  | 9.75  | $C_2$/nF  | 0.478 |
| $C_3$/nF  | 2.87  | $L_{3a}$/uH | 82.8 |
| $C_4$/nF  | 2.62  | $L_{4a}$/uH | 10.35|
| $C_5$/nF  | 55.21 | $R_{e}$/Ω   | 20   |
| $f$/MHz   | 1     | $|V_0|$/V   | 3.18 |

### 3. Establishment of ADRC model

The ADRC constructed by Professor Han Jingqing is mainly composed of tracking differentiator (TD), extended state observer (ESO) and nonlinear state error feedback (NLSEF). Tracking differentiator is an important part of ADRC. The main function of tracking differentiator is to solve the problem of signal extraction and differentiation. Extended state observer is the core of ADRC. Extended state observer (ESO) is an observer based on the idea of state observer, which can observe the extended state by expanding the total disturbance into new state variables and using a special feedback mechanism. The combination control law is to combine the error, error differential and error integral of the transition process in a certain form. For example, the nonlinear controller can be obtained by constructing the function $f$ or the fastest control synthesis function $f_{han}$.

The basic framework of ADRC is shown in Figure 5.[5]

![Fig 5 basic framework of ADRC](image)

### 4. Analysis of simulation results

In this chapter, through the modeling and simulation of the closed-loop LCL ECPT system, the simulation results of open-loop, PID control and ADRC are obtained under the condition of no interference, white noise interference and pulse interference, and the simulation results are compared and analyzed.

#### 4.1. Simulation results of system operation under white noise interference

When the system is given a sine wave with amplitude equal to 14V, the simulation waveform output of LCL ECPT system under three operation modes of open-loop, PID control and ADRC is shown in Fig.6 without external interference input. Table 2 can be obtained by comparing the simulation results of the system under three operation modes without disturbance.

![Fig 6 system voltage output under three operating states without interference](image)
4.2. Simulation results of system operation under white noise interference

The system is given a sine wave whose amplitude is equal to 14V. White noise is added to LCL ECPT system at 0.0002s. The simulation waveform output under open-loop, PID control operation and ADRC operation modes is shown in Fig. 7. Table 3 can be obtained by comparing the simulation results of three operation modes under white noise interference.

![Fig 7 system voltage output under three operating states under white noise interference](image)

| Table 2 simulation results of three operation modes without disturbance |
|---------------------------------------------------------------|
| **performance** | **Overshoot** | **Rise time ($t_r \times 10^{-6}$ s)** | **Adjustment time ($t_s \times 10^{-5}$ s)** | **Phase difference ($\Delta t \times 10^{-5}$ s)** |
|------------------|----------------|----------------------------------|---------------------------------|----------------------------------|
| open loop        | 12.5%          | 11.211                           | 3.69                            | 0.0357                           |
| PID              | 0              | 20.21                            | 2.804                           | 0.024                            |
| ADRC             | 0              | 8.73                             | 0.2792                          | 0.029                            |

4.3. Simulation results of system operation under impulse jamming

The system is given a sine wave whose amplitude is equal to 14V. The simulation waveform output of LCL ECPT system under open-loop, PID control and ADRC operation modes after adding pulse interference is shown in Fig. 8. Table 4 can be obtained by comparing the simulation results of three operation modes under pulse interference.

![Table 3 simulation results of three operation modes under white noise interference](image)

| Table 3 simulation results of three operation modes under white noise interference |
|-----------------------------------------------------------------------------------|
| **performance** | **Overshoot** | **Recovery time ($\times 10^{-5}$ s)** | **Maximum difference ($\Delta t \times 10^{-5}$ s)** |
|------------------|----------------|----------------------------------|----------------------------------|
| open loop        | 70.5%          | 3.7                              | 403.455                          |
| PID              | 42.4%          | 1.9                              | 265.655                          |
| ADRC             | 6.9%           | 0.9                              | 300.644                          |
Fig 8 system voltage output under three operating states in case of pulse interference
Note: from top to bottom are closed-loop given voltage, open-loop operation output, PID control operation output and ADRC operation output

Table 4 simulation results of three operation modes of the system in case of pulse interference

| Performance | Overshoot (\%) | Recovery time (\times 10^{-5}) s |
|-------------|----------------|---------------------------------|
|             | Rising edge of pulse | Pulse falling edge | Rising edge of pulse | Pulse falling edge |
| open loop   | 13.9            | -14.9                   | 3.7                   | 1.3               |
| PID         | 10.2            | -9.6                    | 1.9                   | 0.91              |
| ADRC        | 5.1             | -8.6                    | 0.9                   | 0.79              |

4.4. Simulation results of system operation when system parameters change
After reducing the lowest order parameter of the system transfer function by 50%, the simulation results of the system are shown in fig. 9. When the lowest order parameter of the system is reduced by 50%, the output stability of the system under three operation modes is different, which is similar to that when the parameters are not changed. Table 5 can be obtained by comparing the simulation results of three operation modes when the system parameters change.

Fig 9 simulation results of system operation when parameters of transfer function change
Note: from top to bottom are closed-loop given voltage, open-loop operation output, PID control operation output and ADRC operation output

Table 5 simulation results of three operation modes when system parameters change

| Performance | Minimum amplitude (V) | Maximum amplitude (V) | Amplitude difference (V) |
|-------------|-----------------------|-----------------------|--------------------------|
| open loop   | 6.992                 | 14                   | 2.182 \times 10^{-2}     |
| PID         | 13.9800               | 14.0100              | 2.182 \times 10^{-2}     |
| ADRC        | 13.9982               | 14.0000              | 0.18 \times 10^{-2}      |
5. Conclusion
Through the simulation modeling of LCL type ECPT system under three operation modes of open-loop, PID control and ADRC, the voltage output waveform of the system under the three operation modes without interference, white noise, pulse interference and change of its own parameters is analyzed. When the system has no interference input, the rise time of voltage amplitude under three operation modes is compared $t_r$. Adjustment time $t_a$ and phase lag time $\Delta t$. It is concluded that ADRC has better rapidity under the condition of no overshoot; when the system has white noise interference and pulse interference, the maximum amplitude difference of voltage in ADRC mode is not higher than 50% in PID control mode, and the recovery speed is 2.1 times and 1.2 times of PID control respectively; therefore, the system with ADRC has stronger anti-interference performance and faster response speed. When the system parameters change, the amplitude fluctuation of ADRC is only 8.2% of that under PID control mode. When ADRC is adopted, the robustness is stronger. The LCL ECPT system can have better performance.

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