Circuit Principles of Robust Control Techniques and Their Applications

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Abstract. In the popularity of electric vehicles, dynamic wireless charging technology is an important technology to break the mileage anxiety and realize "charging while running". Some researchers have found the possibility of transferring the robust control system to the dynamic wireless charging technology. Therefore, this study systematically analyses the robust control technology based on inverter and chopper circuits, describes the application effects and application scenarios of this technology in the direction of wireless charging, and shows its advantages and disadvantages at the same time. It is found that the robust control technology can effectively improve the efficiency of wireless charging, as well as the stability of the system. It can be applied in the fields of new energy vehicles and aircraft. In the future, the system complexity and cost of the robust control technique still need to be optimized through further research.

Keywords: Wireless charging, Robust control, Inverter circuit, Chopper circuit.

1 Introduction

In order to save energy and reduce environmental pollution, electric vehicles have been greatly promoted by countries around the world. Due to the limitations of battery capacity and charging infrastructure, charging has become the main bottleneck in the development of electric vehicles. Because wireless charging technology can solve the interface limitations and safety problems faced by traditional conductive charging, it is gradually developing into the main way of charging electric vehicles. However, static wireless charging and wired charging have the same problems of frequent charging, short range, high battery usage, and high cost. Driven by this, dynamic wireless charging technology for electric vehicles has emerged to provide a real-time energy supply to moving electric vehicles through a non-contact method. Its principle is mainly: the use of power supply rails laid below the ground in the form of high-frequency 85kHz alternating magnetic field will be transmitted to the power receiving equipment running on the ground in a certain area of the receiving end of the vehicle, and then to the car battery power supply, you can reduce the capacity and size of the battery, and effectively increase the battery range, to extend its service life [1]. The key link in the robust control technology of energy transfer for wireless charging is

Y. Yue (ed.), *Proceedings of the 2024 International Conference on Mechanics, Electronics Engineering and Automation (ICMEEA 2024)*, Advances in Engineering Research 240,
https://doi.org/10.2991/978-94-6463-518-8_32

the design of inverter and chopper circuits. Currently, it has been shown that the optimal value of the compensation coil parameters can be obtained through optimized calculations to achieve the maximum conversion efficiency while meeting the power demand of the charging load with a large variation of the coupling coefficient: when the coupling coefficient of the system is reduced to about 30%, the output power of the system is still not less than 3 kW, while the conversion efficiency decreases by a very small amount only [2].

The purpose of this paper is to design and explain the principle, structure and workflow of the core inverter and chopper circuits, and further analyse the effects, advantages and disadvantages of the robust control technique and its applications.

2 Introduction to the Circuit Principle of Robust Control Technology

2.1 Introduction to the Principle of Inverter Circuits

An inverter circuit converts DC energy into AC energy. The basic principle of an inverter circuit is as follows: an inverter circuit is made up of two parts: a DC input and an AC output. It generates a sinusoidal waveform on the AC output based on the polarity and magnitude of the DC input voltage for use by other devices. The main component in the inverter circuit is the switching tube, which usually consists of a transistor or field effect transistor. Another central component of the inverter circuit is the filter, which is used to remove any stray waves on the AC output. The principle of operation of an inverter circuit is as follows: In an inverter circuit, the switching tubes are controlled by a switching controller. Since the switching controller generates pulses at a frequency of up to several hundred kilohertz, the switching tubes can be switched on and off rapidly for the purpose of converting direct current to alternating current.

In this paper, a single-phase bridge inverter circuit with a full-bridge inverter circuit circuit is used as an example:

Single-phase bridge inverter circuit:A single-phase bridge circuit is a basic DC/AC inverter circuit.As shown in fig 1, its basic operating principle is:(1) With switches S1 and S3 closed, its load voltage is positive;(2) When switches S2 and S4 are closed, its load voltage is negative, in Fig 1.

The change of load current under resistive load is in phase with the voltage. However, if it is a resistive load, the fundamental wave of the current lags behind the fundamental wave of the voltage. And because of the presence of load inductance, the change of load current is not instantaneous, but a gradually increasing and decreasing process. Its final reflection in the resistance of the voltage waveform is to follow the resistive load current changes.

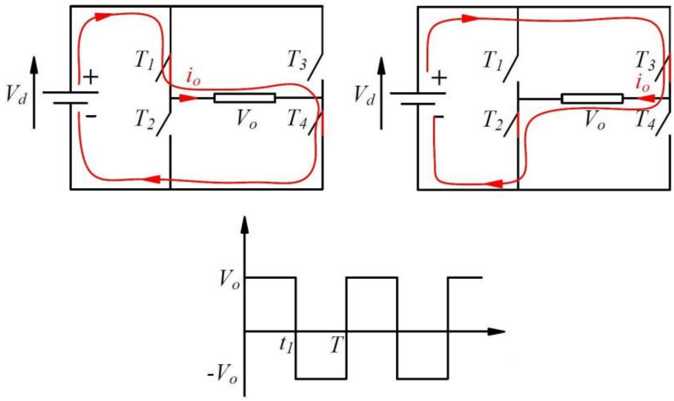

Fig. 1. Single-phase bridge inverter circuit diagram with waveform figure. (Photo/Picture credit : Original）

Principle of operation of a full bridge inverter circuit:A full-bridge inverter circuit mainly involves alternate conduction of switching tubes and AC voltage output from the load.As shown in fig 2, When an input DC power supply is applied to the full-bridge circuit, each switching tube operates in a specific sequence of switching. This sequence typically consists of two 180-degree conduction phases, in each of which two bridge arms are simultaneously on while the other two are off. This alternating on-and-off pattern creates an AC voltage signal with a high-frequency output waveform.With the output transformer, the magnitude and frequency of the voltage can be adjusted and output to the load.

In addition, in a full bridge inverter circuit, the change in load current is not instantaneous but is a gradual process of increasing or decreasing due to the presence of an inductance. This current response is in phase with the voltage, but under resistive inductive loads, the fundamental wave of the current lags behind the fundamental wave of the voltage.

Among them, the researchers used a full-bridge inverter circuit with a single-phase bipolar sinusoidal pulse width modulation method as the object of study, taking the amplitude modulation system r=0.9 or so when the carrier frequency is an odd multiple of the modulating waveform frequency, and taking the amplitude modulation system r=0.5 or so when the carrier frequency is an even multiple of the modulating waveform frequency, in this case the output inverted voltage waveform is of a better quality and the harmonic content is small, and it can be used to improve the Inverter circuit design [3].

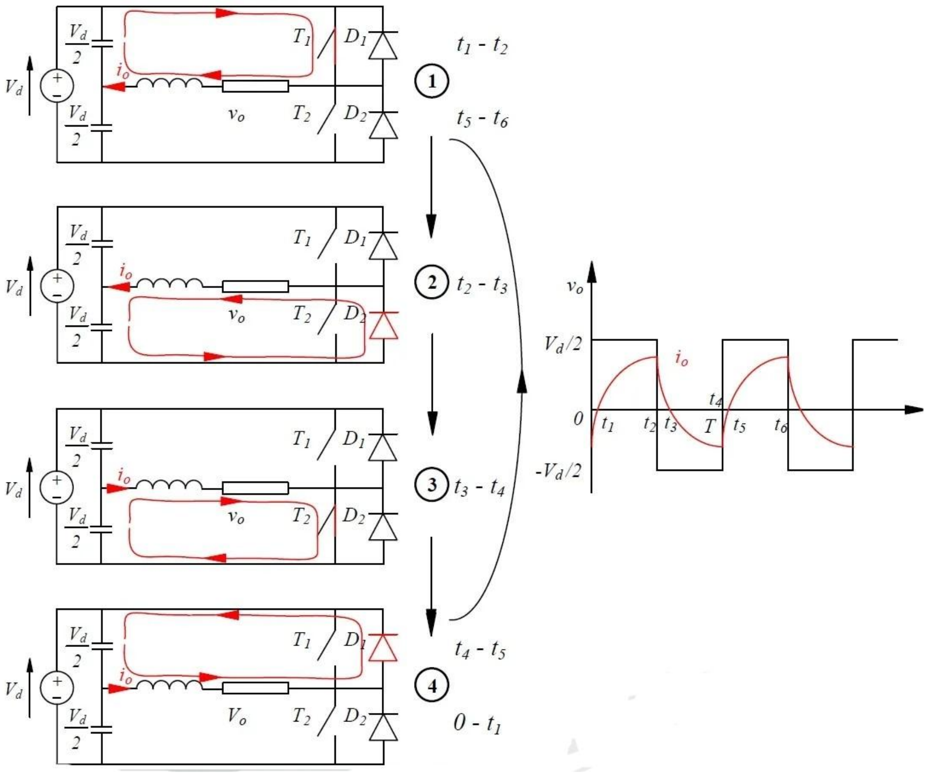

Fig. 2. Full bridge inverter circuit diagram with waveform figure.(Picture credit : Original ）

2.2 Introduction to the Principle of Chopper Circuits

Chopper circuits are circuits that can change DC power to another fixed voltage DC power. The so-called chopper is to "chop off" part of the constant DC voltage, that is, by periodically cutting off the power signal to achieve the regulation of voltage or current. Chopper circuits are commonly used in switching power supplies, inverters, and motor drive systems. The general types of basic chopper circuits include boost chopper circuits, buck chopper circuits, and lift chopper circuits. The focus here is on boost chopper circuits.

Boost Chopper Circuit, the basic boost chopper circuit consists of a switching device, an inductance, a diode and an output filter capacitor. The basic principle is to raise the voltage of the input supply to the desired output level by periodically cutting off and conducting the switching device to achieve storage and release of energy in the inductor. During the cut-off phase, the current is passed through the inductor to store energy, while during the conduction phase, the diode provides a loop to allow the current to continue to flow. The output voltage is precisely controlled by adjusting the operating period and duty cycle of the switching device. A boost chopper circuit with inputs in series for high-frequency auxiliary power DC-DC converter unit for metro vehicles has been investigated, which consists of two sets of the common boost converter inputs in series, and the control of the hairpin waveform is controlled by interleaved control so that the switching devices of this circuit have low voltage and current stresses [4].

In a buck chopper circuit, the basic circuit components are the same as in a boost chopper circuit. When a switching device conducts, current flows from the supply through the inductor. This causes an increase in the energy stored in the inductor. At the same time the voltage at the output also rises. Unlike the boost chopper circuit, the output voltage of the buck chopper circuit remains higher than the input voltage in the on state. When the switching device is switched off, the energy stored in the inductor is transferred to the output through the loop provided by the diode. This reduces the output voltage to the desired level. It is shown that the basic buck chopper circuit, three-phase triple chopper circuit in the same duty cycle control both output voltages are basically the same. They are close to the power supply film multiplied by the duty cycle of the control terminal of the IGBT. The role of three-phase triple chopper circuit is mainly to reduce the harmonic component of the output voltage. However, the harmonic components of the three-phase triple chopper circuit compared to the basic chopper circuit in the numerical difference is small. It acts more as a kind of backup circuit [5].

3 Evaluation of Effects and Applications

3.1 Effectiveness and Applications in Wireless Charging

The effectiveness of the robust control technique is mainly reflected in its design objective, i.e., to design a fixed controller such that the corresponding closed-loop system maintains the desired performance under the action of specified uncertainty perturbations. It aims to ensure that the closed-loop system is able to allow for the maximum uncertainty perturbation while maintaining the desired performance.

In addition, robust control is a control technique that can effectively deal with system uncertainty. Uncertainties include parameter perturbations, external perturbations, and modelling errors. The goal of robust control is to keep the system stable and achieve the desired performance index in the presence of uncertainty. It can enhance the stability in wireless charging for electric vehicles. Researchers at the University of Hong Kong have proposed a two-parameter simultaneous control method for power and maximum efficiency without bilateral communication, where maximum efficiency control is achieved by adjusting the secondary equivalent AC impedance through a DC/DC converter, and output constant power control is achieved by searching for a minimum value of the primary input power. The circuit included can convert DC to AC and effectively control the circuit boost and buck. Experimental studies have shown that following good wiring design rules can significantly reduce ripple and improve the boosting effect, and the problems caused by excessive front-end boosting current are effectively solved by studying the circuit topology [6].

3.2 Analysis of Strengths and Weaknesses

Firstly the robust control system is able to adapt to the uncertainty of the system and maintain the stability and performance of the system even in the presence of parameter changes or external disturbances. The parameters calculated based on the robust optimization model enable the system to satisfy the charging power demand of the load even under the most severe fluctuation of the coupling coefficient, while the efficiency is only reduced by 1% to 2% [2].

Secondly, it can improve the reliability and stability of the system by designing the controller with redundancy. Even in the case of injecting hardware and software failures, the redundant system can still maintain synchronization, provide correct voting outputs, and there is no output perturbation when the main control is switched, and it can automatically adjust the structure, which is very fault-tolerant and meets the design requirements [7].

However, the design of robust control systems is more complex and needs to take into account the uncertainty of the system, which may lead to a more difficult development and debugging process. It may not be able to maintain the performance of the system in the face of extreme uncertainty, such as when the parameters deviate significantly from the design values. The variable structure control technique is a type of robust control, that is robust to system parameter variations and disturbances in sliding mode but also suffers from jitter. This kind of jitter is intolerable in the fields where the accuracy is very demanding such as aerospace and aviation. Some scholars designed a non-singular terminal sliding mode controller based on an improved super-twisting algorithm and proved through physical experiments that it is able to carry out the balance control of bicycle robots more efficiently, with more continuous output, stronger anti-interference ability, and better control effect [8].

In addition, the performance of the robust control system depends on the adjustment of the parameters, which may require frequent adjustments in real operation, increasing the complexity of the system. When the compensation inductance takes other non-optimized values, the efficiency decreases if the output power is increased and decreases if the efficiency is increased [2].

3.3 Other Application Scenarios

First of all, robust control techniques can be applied to flying vehicles. The flight attitude control problem of a vehicle is a multivariate nonlinear control problem. This example is an application of the nonlinear dynamic inverse control law to an unpowered vehicle, which takes inertial uncertainty and aerodynamic moment uncertainty into account, and applies robust control to design the system, and the control scheme adopts a two-loop structure, which corresponds to a fast-varying system and a slow-varying system, respectively. Robust control was created to solve the problem of designing uncertain control systems and provides an effective means to deal with uncertainty. Among them, the Monte Carlo method has limitations such as large computational volume and long time-consuming in the robustness verification of helicopter flight control system, after researching this problem, a traceless transformation method is proposed for the robustness verification of helicopter flight control system, which uses the particle swarm algorithm to solve the parameters to be determined [8]. The helicopter yaw channel is used as an application case to compare the prediction results of the traceless transformation method and the Monte Carlo method for helicopter flight control system robustness validation. The results show that the traceless transform method for the robustness verification of helicopter flight control system significantly improves the computational efficiency and is comparable to the Monte Carlo method in terms of computational accuracy; the method can also be applied to the robustness verification of high-dimensional helicopter flight control system by adjusting the values of the parameters to reduce the distance between the sampling point and the sample centre [9]. This method can also be applied to the robustness verification of high-dimensional or nonlinear helicopter flight control systems by adjusting the parameter values in order to reduce the error, which proves the reliability of the robustness verification of high-dimensional or nonlinear helicopter flight control systems.

Besides, robust control techniques can also be applied to deformable omnidirectional mobile robots. Aiming at the uncertainty problems in the dynamical systems of two different configurations of deformable omnidirectional mobile robots, the researchers proposed an adaptive PD control law based on the Lyapunov stability theory to approximate the uncertainty terms such as friction and external disturbances in the system, and to realize the compensated control of the systems of two configurations, namely, the wheelchair and the gurney [9]. Considering the compensation accuracy and disturbance resistance of the system, a robust term is added to the control law to reduce the approximation error of the algorithm. The proposed adaptive robust PD control law is proved to ensure the stability of the system in deformable omnidirectional mobile robot dynamics by Lyapunov stability theory [10]. Taking the wheelchair configuration as an example, the simulation results show that the algorithm has good trajectory tracking performance, which verifies the effectiveness and feasibility of the algorithm. In turn, it provides an effective reference for the selection of mobile robot motors.

4 Conclusion

In this study, it is found that by designing a controller capable of adjusting the parameters, the robust control technique can cope with the interference of external factors in complex situations and practically improve the efficiency and stability of the dynamic wireless charging technology. Therefore, this technology has practical application possibilities in the field of dynamic wireless charging, which can solve the performance problems of dynamic wireless charging technology to a certain extent and provide strong support for the development of new energy vehicles. This provides a new solution to the current efficiency problem of dynamic wireless charging, which is expected to promote the further development of the field. However, the current study lacks experimental validation, which may lead to a gap between theory and practical application, preventing researchers from accurately assessing the performance of the circuit. Meanwhile, the tuning parameter adjustment of the robust control system increases the complexity of the system, so more effective parameter adjustment methods need to be found to simplify the commissioning and operation of the system. Future research needs to further explore how to reduce cost while maintaining performance and improve energy efficiency to meet the growing market demand for new energy vehicles.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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