Digital controller for electric vehicle synchronous motor rotor

Weihua Chen*

State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources

North China Electric Power University, Beijing 102206, China

Received 1 March 2014, www.cmnt.lv

Abstract

At present, the number of electric vehicle is increasing, and, in case of big vehicle speed change, the vehicle motor cannot be used efficiently. In order to resolve this problem, it is necessary to improve the topological structure and control strategy, and design a new converter. In this paper, we apply a two-channel synchronous Buck converter. The main circuit is to achieve the maximum power output by the stage regulation, while the improved converter topology realizes the overall system function. The experimental results show that the new converter has superior performance in big vehicle speed change, and has the high quality energy output. This research has an important practical significance to improve the utilization of renewable energy.

Keywords: power system, electric vehicle, digital controller, inverter, converter

1 Introduction

With new kind of vehicle developing, electric vehicle is getting more and more attention of researchers [1]. Now the utilization of drive motor for electric vehicle is usually in the way of the asynchronous motor mode. Asynchronous motor is with low price, but the poor performance. So its application is limited [2-4]. While synchronous motor has a lot of advantages, such as good mechanical characteristic and adjustable air gap. It may operate efficiently in the big speed range with greatly improved power efficiency and reduced operation and maintenance costs. Synchronous motor has become an important development direction in drive motor for electric vehicle, characterized by being more economical, convenient, and practical.

The research on the utilization of synchronous motor for ele-ctric vehicle mainly concentrates on synchronous motor physical structure, while paying little attention to how to control synchronous motor. The resulting consequence is the fact that synchronous motor does not operate perfectly for electric vehicle. Traffic jam is very serious in many large cities all over the world, vehicles have to start and strop frequently, so the traditional synchronous motor control cannot gain synchronous motor effective performance. This research aims to improve the performance of electric vehicle under big speed range by designing a new excitation converter control strategy for synchronous motor [5-7].

Some research has been done on the topology structure and control strategy of the excitation converter. The excitation converter used the two-channel synchronous Buck circuit topology. On the control strategy, phased control strategy and adaptive PI control method based online parameter adjustment were used. DSP chip TMS320F2812 was used as the control core to realize the switch controlling, data processing, communication and other functions. Through the improvement of excitation converter topology and control strategy, we can improve the performance of ecitation converter and the performance of synchronous motor under big speed range, and promote the development and utilization of electric vehicle.

2 Excitation converter topology

The excitation converter adopts the two-channel synchronous Buck parallel connection, as shown in Figure 1. The purpose of the two-channel synchronous Buck parallel connection is to increase the output current ripple frequency and reduce its amplitude. It can improve the dynamic response speed by reducing the output filter inductor. Under the same power output condition, the two-channel synchronous Buck parallel connection preferment [8-13].

Double closed loop is composed of voltage loop and current loop independently, as shown in Figure 1. It can realize the constant pressure output or constant current output. Firstly, Voltage loop sample the output voltage of *Vo*, and then compare it with the set voltage value *Vr*. The difference between the two voltages is put into the adaptive PI regulator, shown in the dashed box. Current loop is with the same voltage loop. Adaptive PI regulator can adjust proportion coefficient KP and integral coefficient KI. This can be used to realize cycle current or voltage control and overcurrent protection. Voltage loop work during quick response stage in the converter, while current loop work during the steady constant current stage in the converter.

***Corresponding author** e-mail: cwhwc@163.com

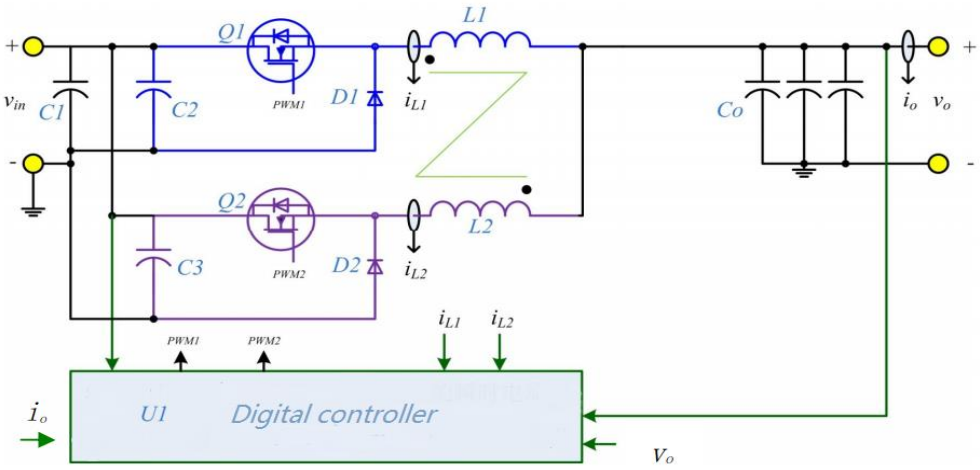


FIGURE 1 Two channel synchronous Buck converter main circuit topology diagram

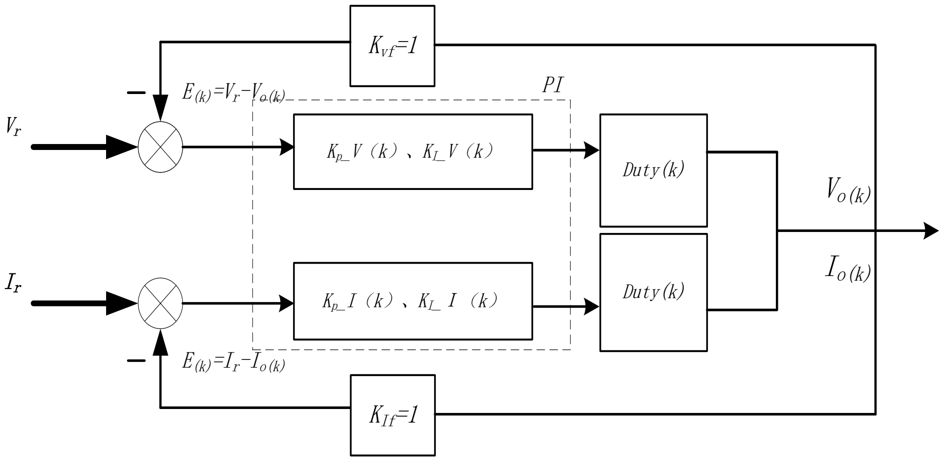


FIGURE 2 Double closed loop control structure diagram

Here introduced several parameters: *Vr* is the symbol of converter expected output voltage value (equal to the desired output current of *Ir* with the equivalent resistance of Re product, Re identification, see section third). *Vin* is the converter input voltage *Vo* converter; the actual output voltage. *D* is the power tube gate driving signal duty ratio of PWM wave; *ΔV* is expected output voltage and the actual output voltage difference, namely Delta *V*=*Vr*-*Vo*.

In electric vehicle, torque speed requirements change quickly. The rotor excitation current need to response quickly, namely the excitation converter can make rapid response to the different output needs. At the same time the overshoot and steady state error of the output are smaller. But the PI controller with fixed parameters is difficult to meet the requirements. This paper presents a simple, efficient adaptive PI controller to solve the problem [14, 15].

The mathematical equations for the adaptive PI controller are

$$\begin{aligned}\Delta u(k) &= u(k)\text{-}u(k\text{-}1)\\ &= K_p(e(k)\text{-}e(k\text{-}1))+K_I e(k)\text{,}\end{aligned} \tag{1}$$

where the two parameter K_P, K_I tuning is adaptive PI control key points.

In order to make the converter voltage output can quickly track the desired voltage value, and the start-up phase voltage overshoot in a proper range, let the coefficient K_p is expected to duty ratio divided by the voltage difference

$$K_p = \frac{d}{\Delta V} \tag{2}$$

and let

$$d = \frac{V_r}{V_{in}}. \tag{3}$$

So coefficient K_p is

$$K_p = \frac{k_1 \times (k_2 \times V_r\text{-}V_{start})}{V_{in} \times (k_2 \times V_r\text{-}V_o)}, \tag{4}$$

where k_1 is the correction coefficient, k_2 is the actual voltage output and the expected voltage output ratio from fast response stage switching to a steady flow stage. By many tests, k_2 is from 0.85 to 0.9. Because the voltage close loop control begin at the end of soft starting, so we need to subtract voltage V_{start} at the soft start end time.

In addition, let

$$K_I = \frac{K_P}{k_3}, \tag{5}$$

where k_3 is the coefficient of integral coefficient.

3 Converter control strategy

3.1 CONVERTER CONTROL STRATEGY

The work state of converter is divided into soft start stage, fast response stage and steady flow stage. So, the converter control strategy is divided also.

1) Soft start stage. The converter begins by soft start. The voltage output rises from zero to 8 percent of desired voltage value. In this stage, the duty ratio of PWM increases gradually, while the converter voltage output and current output and increases slowly. The purpose of the soft start is to preheat the power devices and circuits. Improving output steadily to prevent overshoot accident. On the other hand, it can identify load parameter. If we do not set the soft start of the converter in the start-up stage, the power switching devices work at the condition with the duty cycle of 100%. So there will be a lot of surge current into the output capacitor. Sometimes, the output voltage overshoot are large. And the surge current may also damage switch tube and other devices. Using the strategy of soft start can eliminate the surge current and avoid the overshoot of output voltage.

2) Fast response stage. In the fast response stage, in order to make the converter voltage output and current output can reach near the given value rapidly; voltage loop with adaptive PI controller is used to reduce the values of voltage output and the current output rise time effectively.

3) Steady flow stage. When the value of voltage output reaches ninety percent of the expected voltage output value, it is the time to be steady flow stage. At this stage, a current loop with adaptive PI controller is used.

3.2 PARAMETER IDENTIFICATION

In the soft startup stage, the control system gets the converter values of voltage output and current output through sensors. The excitation coil resistance is calculated on-line sometimes to obtain the equivalent resistance value with the method of least squares. The biggest advantage of online parameter identification is that effects factors such as temperature, rotation and others on the excitation coil resistance would be contained in the identification parameters naturally once the parameters identification finished. And it is easy to implement and calculation. But each the identifycation parameter may be different. The purpose of parameter identification is to provide the basis parameters for adaptive PI control.

4 Communication and protocol

The integrated control system of electric vehicle covers the parameters of motor stator, rotor, battery's working condition, vehicle speed, and the operation of the driver. The CAN bus technology is used to connect the device for obtaining the above parameters. It is the key to realize the electric vehicle set control. As a multi machine serial communication protocol, the CAN protocol is mainly used for network communication with multi node. The data frames for the CAN protocol is shown in Figure 3. As a practical application, designers need to develop communication protocol at the top level satisfied with their own project. Designers need to fill the data field in the data frame and to set the standard communication rate.

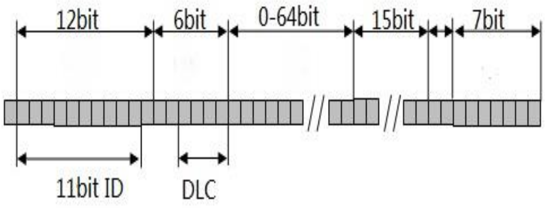


FIGURE 3 Schematic diagram of CAN standard frame format

Considering the communication between excitation converter system and other electric vehicles modules, the standard data frame is used in the paper. The data length is 8 bytes. A kind of simple and effective communication protocol top layer is made. Five communication frames are designed. They are frame 1, frame 2, frame 3, converter output frame, converter device temperature frame respectively. Frame 1, frame 2, and frame 3 are sent from the stator side controller to converter. Converter output frame and converter device temperature frame are sent from converter to the stator side controller. As shown in Table 1-5.

TABLE 1 CAN communication protocol - control frame 1

Name	Begin-end	Unit	Reset value	Smallest value	Biggest value
Inverter_Fault _flag	3-4	-	0	0	3
Converter_Reset _Request	5-6	-	0	0	3
Converter_Enable _Disable	7-8	-	0	0	3
Field_Voltage _Limit	17-32	V	250	0	250
Field_Current _Limit	33-48	A	20	0	20

TABLE 2 CAN communication protocol - control frame 2

Name	Begin-end	Unit	Reset value	Smallest value	Biggest value
Output_Current _Command	1-16	-	0	0	200
Command _Check_Sum	17-25	-	0	0	255

TABLE 3 CAN communication protocol - control frame 3

Name	Begin-end	Unit	Reset value	Smallest value	Biggest value
Converter_Fault _Signal	1-4	-	0	0	15
Converter _Output_Status	5-6	-	0	0	3
Converter_StatusValid	7-8	-	0	0	3
Converter_Field _Voltage_Limit	17-32	V	0	0	250
Converter_Field _Current_Limit	33-48	A	0	0	20

TABLE 4 CAN communication protocol - control frame 4

Name	Begin-end	Unit	Reset value	Smallest value	Biggest value
Field_Coil_Resistance	1-16	Ω	0	0	1000
Real_Converter _Output_Voltage	17-32	V	0	0	250
Real_Converter _Output_Current	33-48	A	0	0	20
Real_Converter _Output_Power	49-64	W	0	0	2500

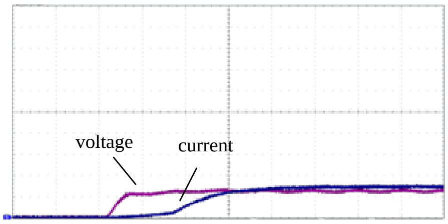
TABLE 5 CAN communication protocol - control frame 5

Name	Begin-end	Unit	Reset value	Smallest value	Biggest value
Field_Coil_Temperature	1-16	℃	0	-50	250
Switching_Component_Temperature	17-32	℃	0	-50	250
Inductor_Temperature	33-48	℃	0	-50	250

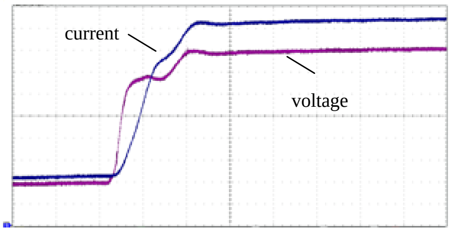
In this design physical implementation of CAN communication relies on the CAN module meets the CAN2.0B protocol standard built-in TMS320F2812 chip. The CAN module communication rate is up to 1Mbps. And it is of low power mode and CAN bus wake-up function. Considering the practical engineering, the configuration of CAN bit rate is 500bps. In the experiment, the PC with USB2CAN function is used for the simulation of stator side controller and converter doing CAN communication and control. It is obviously that the CAN communication is of good reliability.

5 Case studying

A prototype is built to make the related tests. And the test results are recorded. Figure 4 and Figure 5 is the converter start-up test wave form and dynamic response wave form respectively. Figure 6 is the steady state ripple wave form converter. In the experiment, resistors and inductors are used to simulate converter load. The rated load is a resistor of 35Ω and a series inductance 650mH.

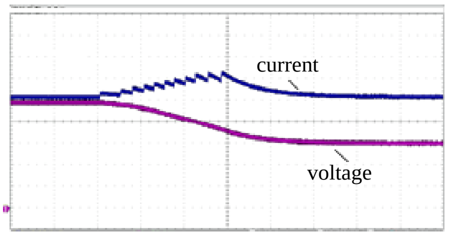


a) Soft start stage

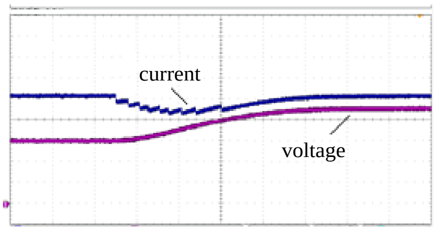


b) Regulating stage

FIGURE 4 Test waveforms at rated load starting



a) Load decreasing



b) Load increasing

FIGURE 5 Test waveforms at rated load starting

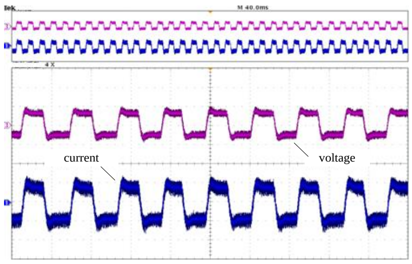


FIGURE 6 Voltage and current output ripple peak value

As we can see from Figure 4, the output values increase rapidly during the converter start-up stage. The response time is less than 100ms. The voltage overshoot is less than 15V. The current overshoot is less than 1A. It can be seen from Figure 5 that converter dynamic responses rapidly when load changes. The response time is less than 200ms. It can be seen from Figure 6 that the converter steady state voltage ripple is less than 1V and that the steady state current ripple is less than 50mA.

In addition, the converter power and efficiency is test, as the results shown in Table 6. In the two long tests, converter has a stable output. The values of output power are more than 800 watts. The values of efficiency are more than 95%. The above values satisfy the requirements of power and efficiency.

5 Conclusions

This paper describes the main design ideas of the synchronous motor rotor excitation converter for electric vehicles. The two channels synchronous Buck interleaves. The topology of converter is optimized. The control stage and adaptive PI converter are used. It can quickly achieve the desired output value during the different output demand. Making CAN communication protocol is not only to meet the communication needs of converter and stator side controller, but also provides reference and space for electric vehicles to build the more complex internal communication network in the future. The prototype is with good output and regulation performance. It meets the basic requirements of application in vehicle rotor excitation converter.

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Author

Weihua Chen, born on May 13, 1978, China

Current position, grades: a researcher in North China Electric Power University.
University studies: M.S. and Ph.D. degree from North China Electrical Power University and Zhejiang University, China in 2003 and 2007.
Scientific interest: automation, renewable energy, and power system stability and control.
Publications: 2 papers.