Proceedings of the 4th International Conference on Machine Learning and Automation
DOI: 10.54254/2755-2721/2026.36912

Research on Hardware Design of a DSP-Based Drive Controller for In-Wheel Motors in New Energy Vehicles

Siyu Zhang

School of Electrical and Electronic Engineering, Hubei University of Technology, Wuhan, China
1798925000@qq.com

Abstract. The automotive industry starts the process of transformation and upgrading, and new energy vehicles gradually take an important position. There are two forms of electric drive technology, centralized and distributed. In-wheel motors belong to the distributed category. It integrates the drive motor into the wheel hub, eliminates mechanical transmission components, has low power loss and relatively flexible layout, can independently distribute the torque of the four wheels and recover energy. Most high-power vehicles use three-phase permanent magnet synchronous motors. However, its high-voltage controller needs to have characteristics such as high-voltage resistance, which has certain constraints on hardware design. This article focuses on the permanent magnet synchronous in-wheel motor and starts to construct a drive control hardware system with a digital signal processor (DSP) as the core. Research scope: The first part analyzes the current research status at home and abroad, compares the advantages and disadvantages of various in-wheel motors, focuses on the development process of permanent magnet synchronous drive control, and highlights the value of choosing it; the second part carries out control hardware design, explains the principles of the hardware and circuit parameters, and the system takes the DSP chip as the core, including circuits such as power conversio.

Keywords: New Energy Vehicles, Distributed Drive Technology, In-Wheel Motor, Permanent Magnet Synchronous Motor

1. Introduction

In order to achieve the goals of carbon peaking and carbon neutrality and promote the transformation and upgrading of the automobile industry, China has promulgated the "Development Plan for the New Energy Automobile Industry (2021 - 2035)" and actively promoted the wide application of electric vehicles with policy measures. Driven by both policies and the market, the new energy automobile industry in China has shown an explosive growth trend. During 2020 - 2025, the sales volume has been continuously increasing and has ranked first in production and sales worldwide for eight consecutive years. The penetration rate of passenger cars has been continuously increasing, and a complete and independent industrial chain has been established [1, 2]. By 2025, the export volume will reach 6.23 million and still remain the first in the world. At the international level, Europe promotes automobile enterprises to turn to electrification through strict regulations, and it is expected that the sales volume of electric models will be about 3.12 million by 2025; the

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.36912

United States supports by means of subsidy measures, and the sales volume of electric models will be about 1.78 million; Japan and South Korea focus on the renewal and iteration of technologies such as solid - state batteries, but the promotion of automobile electrification is relatively slow, and the competition in the automobile field is becoming more and more intense worldwide [3].When there are major progressions in the entire automotive market, the key technologies of new energy vehicles are also advancing rapidly. The electric drive system is evolving towards integration, transforming from a three-in-one component to a multi-in-one architecture mode. In this system, distributed drive places the motor on the side or inside of the wheel, removing traditional transmission components and achieving independent torque control for each wheel. The transmission loss of in-wheel motors is quite small. However, due to the increase in unsprung mass and sealing, there are strict requirements for heat dissipation, resulting in it not having been mass-produced yet. Its operation relies on a high-performance motor controller, and the dynamic response and safety reliability of the in-wheel motor are determined by the hardware circuit of the controller. Therefore, this article focuses on exploring the detailed design of the in-wheel motor control circuit.

2. Concept and application of in-wheel motors

2.1. Concept and working principle of in-wheel motors

The motor in the hub integrates the drive motor into the hub, removes mechanical components such as the transmission shaft and differential, and achieves the independent drive of the wheel. Its principle is based on the electromagnetic induction phenomenon. When an alternating current passes through the stator windings, a rotating magnetic field is generated, and this magnetic field drives the rotor to rotate, thereby directly making the wheel rotate. It can realize high transmission efficiency and flexible chassis layout, and has independent torque control ability, but there are engineering-level problems such as increased unsprung mass, difficult heat dissipation, and strict sealing requirements [4].

2.2. Classification of in-wheel motors

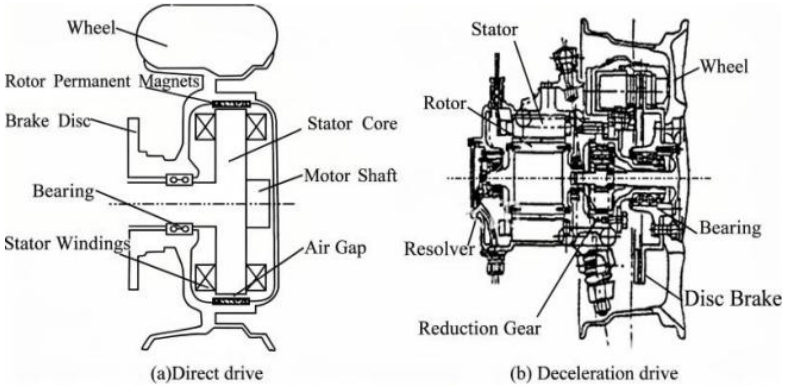


Figure 1. Schematic diagrams of the two typical in-wheel drive configurations

Hub motor includes two types. One is the reduction drive type, which has an inner rotor and a reducer. It is small in size and has strong climbing ability, but there is wear and noise problems. The other is the direct drive type, which uses an outer rotor for direct drive. It has a simple structure and rapid response, but it is large in size and consumes more power at low speeds. Figure 1 shows the

DOI: 10.54254/2755-2721/2026.36912

arrangement of the two types of in-wheel drives, and Table 1 compares the advantages and disadvantages of the two.

Table 1. Comparison of advantages and disadvantages of the two drive configurations for in-wheel motors

Classification	The reduction-drive	The direct-drive type
Form	Install the high--speed inner-rotor motor with the reducer between the motor and the wheel hub.	Generally speaking, the out-er rotor of a low-speed outer rotor motor is directly installed on the hub.
Maximum motor speed	10000r/min	1500r/min
Advantage	With the characteristics of small volume, light weight, good climbing performance, high transmission ratio, efficient power output and stable torque at low speed.	With small axial size, rapid dynamic response, efficient transmission efficiency, convenient and compact drive wheel assembly and low maintenance cost.
Disadvantage	The gears of the planetary reducer are easy to wear, which in turn makes its service life shorter. At the same time, there are also problems such as poor heat dissipation, high noise and difficult lubrication.	The weight and volume are both large. When the motor is transmitting large torque and accompanied by high current conditions, the service life will be shortened. Moreover, the range of peak efficiency is relatively narrow. Once the load current exceeds the fixed value, the efficiency will decline rapidly.

Motors can be divided into categories such as permanent magnet synchronous, brushless DC, induction, switched reluctance, etc. according to types. Among them, permanent magnet synchronous motors have advantages such as high efficiency, high power density, and good control accuracy, and have become the mainstream choice for heavy-duty passenger and commercial vehicles [5-7]. Table 2 presents the characteristic situations of three mainstream motors.

Table 2. Classification and comparison of in-wheel motors

Classification of motor	Advantage	Disadvantage
Permanent magnet motor	With precise control performance, low noise level, small moment of inertia, high power density value, compact volume form, excellent efficiency level and good power factor condition.	Permanent magnets are easy to lose magnetism, and the control circuit and related models of the motor are quite complicated.
DC motor	The motor control is simple and skilled.	Need to be maintained frequently, relatively large in size, high in cost, and low in maximum speed.

DOI: 10.54254/2755-2721/2026.36912

Table 2. (continued)

Asynchronous motor	Low consumption, simple structure, fast speed, light sound, stable operation, strong reliability.	Poor operation regulation ability, too high current at startup, low motor efficiency, complicated operation, and low power density.

2.3. Domestic and international research and vehicle applications of in-wheel motors

2.3.1. Overseas research and industrialization of in-wheel motors

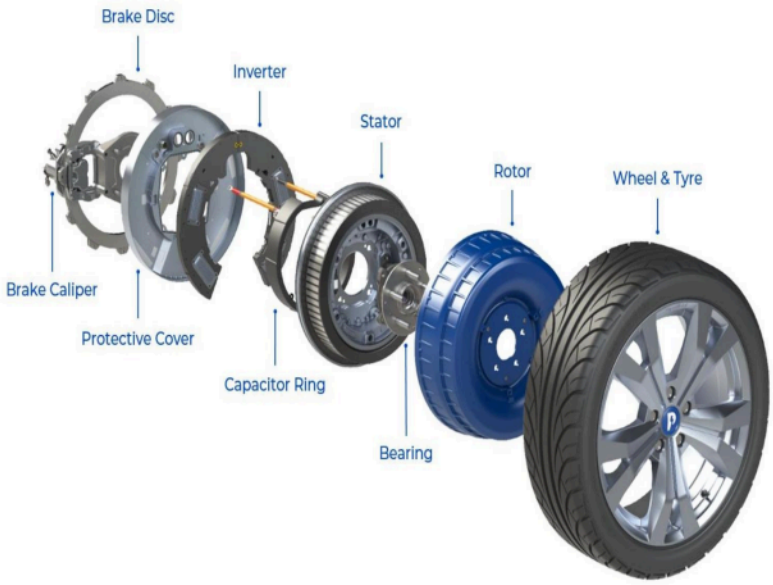


Figure 2. Structure of the Pd18 in-wheel motor

The research and development of in-wheel motors started earlier than that in Europe, the United States and- Japan, and directly reached the situation of large-scale production with the reduction drive technology route in many regions.Protean Electric in Europe (UK) is the world's leading in--wheel motor enterprise. Its Pd18 in-wheel motor adopts a permanent magnet synchronous design, and the peak torque of a single device reaches 1250N·m.The Elaphe company in Slovenia has developed the SonicX hub motor platform, which adopts the direct drive method. When the wheels are speed-controlled, it is twenty times faster than the traditional system, and thus can improve the vehicle performance by 15%. The ultrathin motor of Sonic1 is installed inside the 21-inch rim, which can generate 268 horsepower and 102 N·m of torque. The technical specifications are at the world-leading level, and this motor has entered the small-batch production stage. Figure 2 shows the structure of the Pd18 hub motor [4], and Figure 3 shows the relevant platform of the SonicX hub motor.

DOI: 10.54254/2755-2721/2026.36912



Figure 3. Sonic X in-wheel motor platform

In April 2026, Protean announced a partnership with the Renault Group. Its technology will be deployed in the Renault 5 Turbo 3E electric supercar. The system delivers 555 hp and accelerates from 0 to 100 km/h in under 3.5 seconds. This marks the first large-scale application of in-wheel motors in mass-produced passenger cars in Europe.Figure 4 presents the structure of the Renault 5 Turbo 3E.In Japan, Professor Hiroshi Shimizu's team at Keio University has been conducting research on in-wheel motor drive systems since the 1980s. In 2004, the team, together with 38 companies including Meidensha, launched the Eliica (Electric Lithium-Ion Car) – an eight-wheel, four-axle electric vehicle. The vehicle features a unique four-axle eight-wheel layout. Each wheel houses an independent in-wheel motor. Each motor outputs about 80 hp (59 kW), and the total system power reaches 640 hp. Figure 5 shows the eight-motor-wheel-drive vehicle, Eliica.

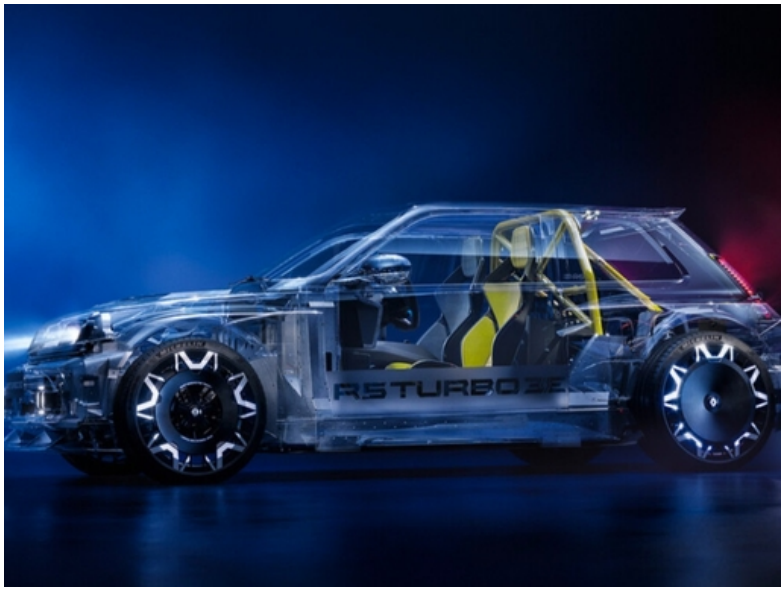


Figure 4. Structure of the Renault 5 Turbo 3E

DOI: 10.54254/2755-2721/2026.36912



Figure 5. The eight-motor-wheel-drive vehicle Ellica

2.3.2. Domestic research and mass production breakthroughs of in-wheel motors

The research and development of new energy vehicles in China started relatively late. In the past decade, it has achieved major breakthroughs with the rapid development of the industry. At the technical level, Dongfeng and universities lead national projects. The Harbin Institute of Technology team has developed a new winding stator structure, innovatively improving torque density and efficiency, and its prototype has exceeded the established goals. In the mass production process, in December 2025, Dongfeng welcomed the announcement of the first distributed four-wheel drive passenger car. The eπ007 hub motor version is equipped with four independent motors, with a power of 400 kilowatts, a 20% increase in space utilization rate, and entered the announcement list of the Ministry of Industry and Information Technology. The recommended national standard related to electric vehicle hub motor systems is led by Dongfeng to formulate, filling the gap in this field. The whole set of motors has been mass-produced, but there are defects in the high-voltage large-current controller, such as the lack of adaptability solutions, the lack of independent hardware protection, and the poor ability to resist electromagnetic interference. This article focuses on exploring hardware design to solve such problems.

3. Hardware circuit design of the controller

3.1. Overall hardware architecture of the controller circuit

The in-wheel motor controller adopts a standardized modular hardware architecture, with clear overall functional partitioning. The system block diagram is shown in Figure 6.The complete unit consists of eight functional modules: power conversion, main control core, power drive inverter, voltage and current sampling, rotor position detection, independent hardware protection, CAN vehicle communication, and temperature and humidity acquisition. In addition, it includes basic peripheral circuits such as a DSP minimum system, clock, and reset circuitry.The 12 V on-board low-voltage supply is stepped down through DC-DC converters, LDO regulators, and isolated power supplies. These stages output multiple adapted voltages to power the main control and peripheral devices. The DSP generates six PWM signals to drive the power inverter bridge. It simultaneously collects motor current, bus voltage, and rotor Hall position signals. The hardware protection loop monitors faults in real time and quickly cuts off the drive. The CAN bus handles data exchange with the vehicle controller. The temperature and humidity module acquires ambient

DOI: 10.54254/2755-2721/2026.36912

parameters inside the electronic control compartment. This modular design facilitates hardware debugging, fault localization, and future iterative optimization [4].

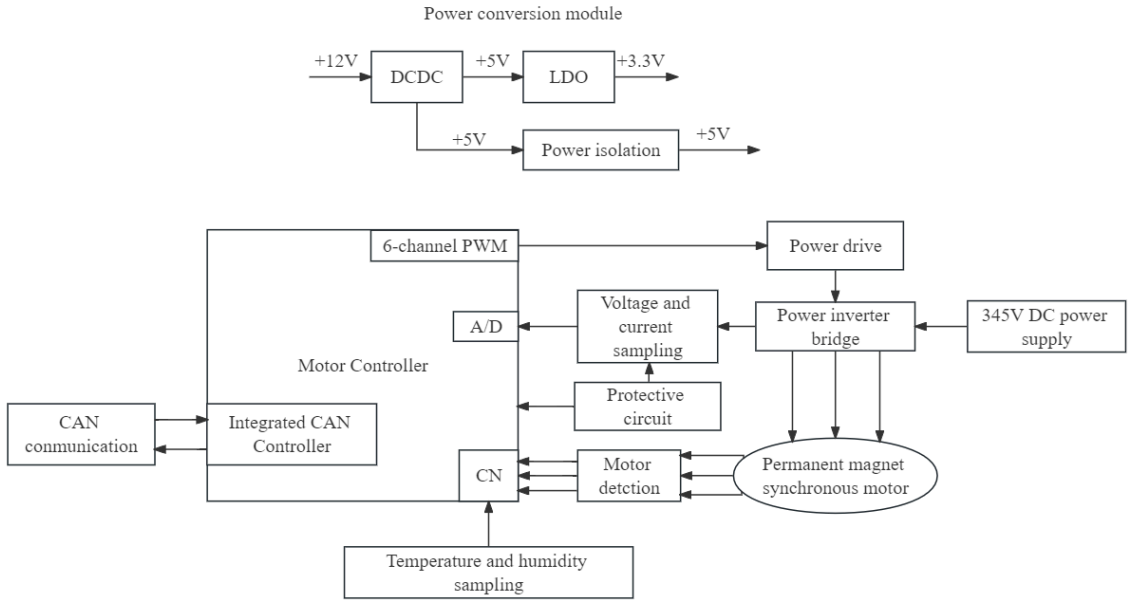


Figure 6. Hardware architecture diagram of the motor control system

3.2. Main control chip and its peripheral circuits

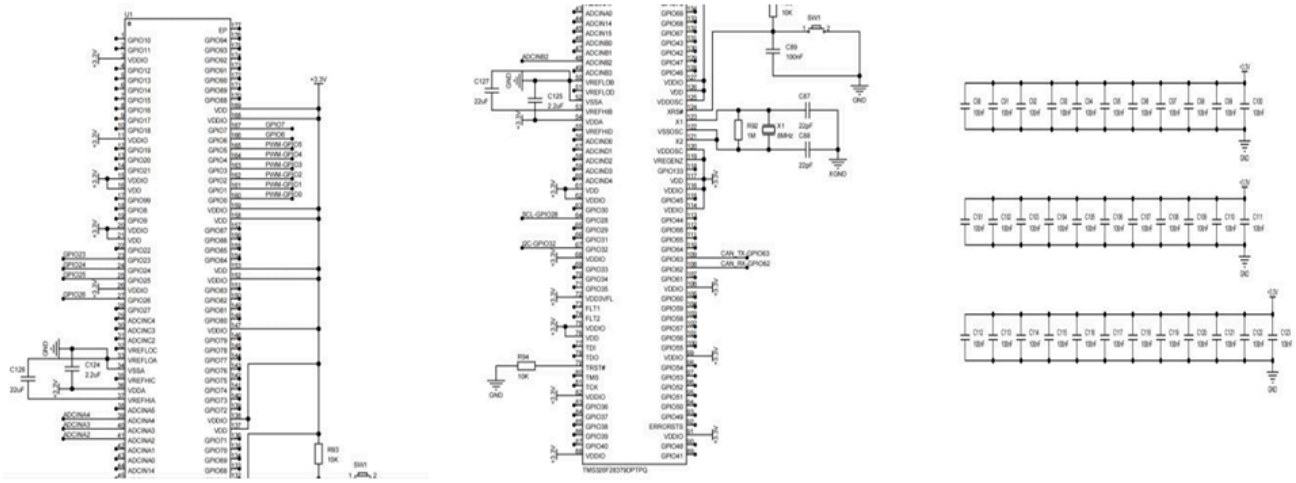


Figure 7. DSP minimum system circuit

This system adopts the TMS320F28379DPTPQ dual-core floating-point digital signal processor as the main control chip. It can be adapted to the harsh working conditions of the 345V high-voltage hub motor and has characteristics such as high real-time control. The dual floating-point cores of this chip are partitioned. One is used for operations such as FOC vector control, and the other is responsible for tasks such as CAN communication, which can avoid control delay. It integrates high-precision synchronous analog-digital converters, etc., and has sufficient general-purpose input and output pins. It can achieve motor control and other work without additional expansion. It also

DOI: 10.54254/2755-2721/2026.36912

supports peripheral circuits such as power decoupling. A 100nF ceramic decoupling capacitor is connected in parallel at the power pin to suppress noise to ensure stability [8, 9]. Figure 7 shows the DSP minimum system.

3.3. Power inverter bridge circuit

This three-phase two-level inverter circuit obtains six complementary pulse width modulation (PWM) signals from the digital signal processor (DSP), inverts the 345V DC power supply into a three-phase AC power with variable frequency and voltage to drive the hub motor. The three-phase bridge arms have the same structure [10]. Each bridge arm adopts the IR2110 gate driver integrated circuit. The SD pin has a microsecond-level hardware shutdown protection function. A 300Ω current limiting resistor can be connected in series to the PWM signal path to achieve the purpose of suppressing electromagnetic interference (EMI) and isolating high-voltage noise to protect the digital signal processor (DSP) port. The bootstrap circuit includes a diode and a capacitor with a capacity of 68nF. Its function is to provide a floating power supply for the high-voltage side switch and prevent the reverse current of the high voltage. This power device is an IGBT with a rating of 650V and 75A, which has sufficient voltage margin. A current limiting resistor and an RC buffer circuit are connected at the gate to suppress voltage oscillation. A 100μF electrolytic capacitor is connected to the DC bus to buffer the surge of the load voltage. The protection and anti-interference design on the hardware side is very comprehensive, which can meet the needs of hard acceleration and heavy-load climbing. Figure 8 shows the three-phase U-phase power drive circuit.

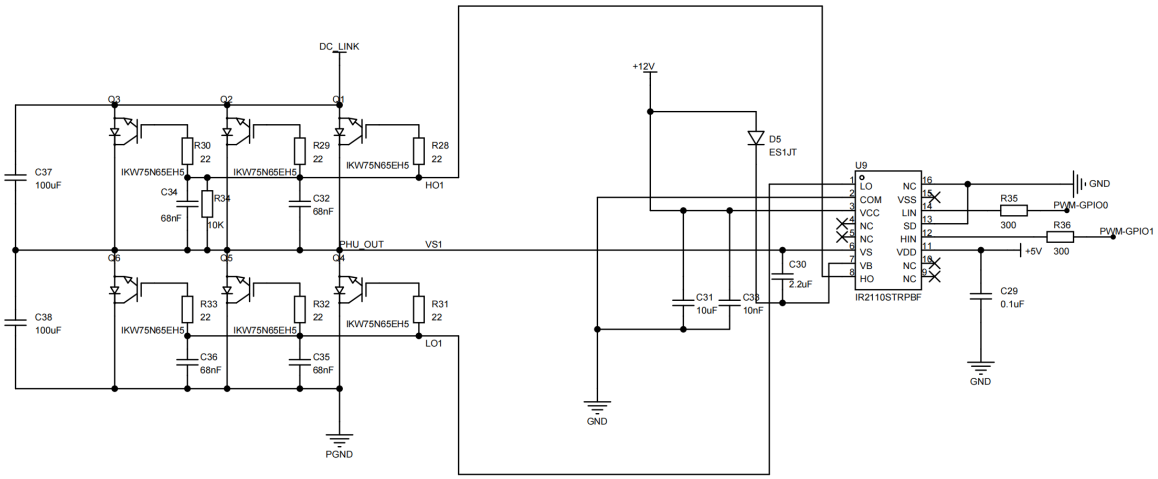


Figure 8. Phase U power drive circuit

3.4. Power conversion circuit

The power supply circuit adopts a two-stage regulation framework, including a DC-DC converter and an LDO. The input is 12V. This design has high conversion efficiency and low noise characteristics for low-voltage power supplies. The B0505S isolation power supply is used for the electrical isolation of the CAN bus, realizing the distinction between high-voltage electricity and low-voltage electricity, and suppressing electromagnetic crosstalk. In addition, three power rail LED indicator branches are added to help fault troubleshooting. Each branch supplies power to the main control, communication, and power peripheral devices respectively, adapting to different voltage requirements [11, 12].

DOI: 10.54254/2755-2721/2026.36912

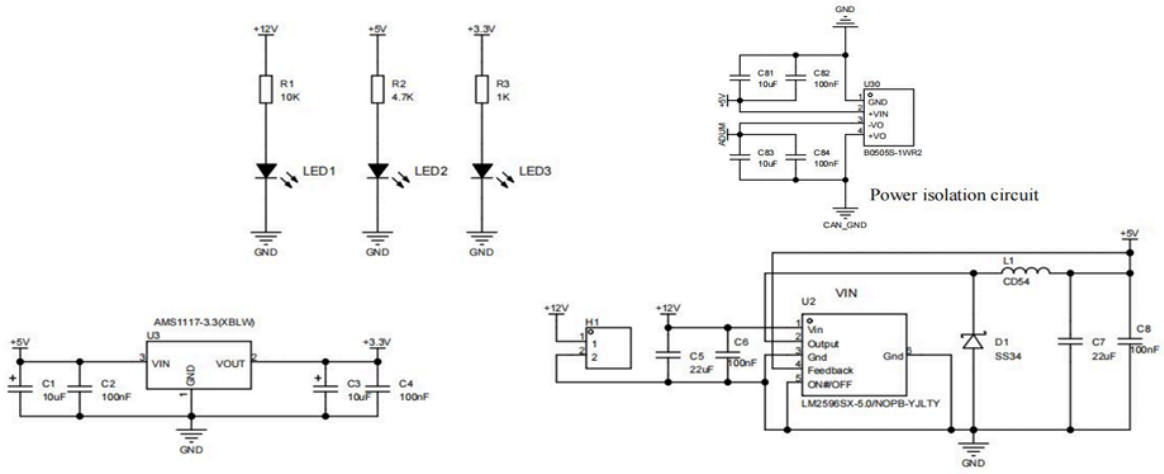


Figure 9. Power conversion circuit

3.5. Current and voltage sampling circuits

To achieve the closed-loop vector control of the motor, the system is equipped with multiple isolated sampling circuits to obtain real-time data such as the currents of the three-phase windings, the current of the total DC bus, and the voltage of the high-voltage bus, and then transmit these data to the ADC inside the DSP for analog-to-digital conversion. This section covers two parts: current sampling and voltage sampling, which are described respectively.

3.5.1. Current sampling circuit

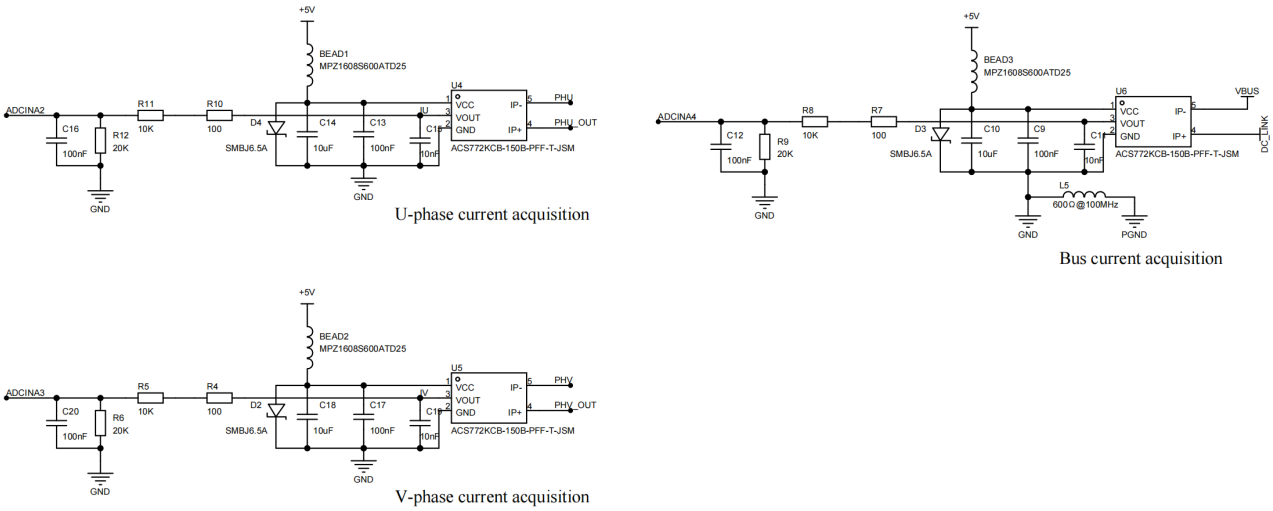


Figure 10. Current sampling circuit

The current sampling circuit contains three channels, namely the U-phase winding, the V-phase winding, and the DC bus. The ACS772 Hall effect current sensor is used for the electrical isolation detection of the three channels, and each channel is powered by +5V. Ferrite beads are connected in series in the power line to suppress high-frequency noise, and the SMBJ6.5A bidirectional TVS diode is connected at the input end to resist surge and electrostatic conditions. The 10μF, 100nF, and 10nF decoupling capacitors are used to smooth the waveform at the sensor output end. The output

DOI: 10.54254/2755-2721/2026.36912

analog signal passes through a 100 Ω current-limiting resistor, a resistor divider composed of 10kΩ and 20kΩ resistors, and an RC low-pass filter network in sequence. The filtered signal is transmitted to the ADCINA2, ADCINA3, and ADCINA4 channels of the DSP [13]. In the path of the DC bus current, an additional ferrite bead is added to separate the power ground and the digital ground to block switching noise, thereby improving the accuracy of sampling. Figure 10 is this circuit.

3.5.2. Voltage sampling circuit

For the bus voltage sampling circuit of the 345V high-voltage D-C bus, an isolated resistor voltage divider and a regulation circuit are adopted. The high-voltage of the DC l-ink is divided by a series of 1MΩ high-value resistors, and the divided voltage signal enters the AMC1301 isolated operational amplifier to realize the isolation of high voltage and low voltage, thus eliminating -the risk of the high voltage puncturing the main controller. The differential output of the isolation amplifier is connected to the TLV9001 single-channel operational amplifier (configured as a noninverting amplifier) to make the signal adapt to the 3.3V input range of the DSPADC. An RC filter is set around the operational amplifier -to remove ripple noise. The finally adjusted voltage signal is sent to the DSPADCINB2 pin- through an RC low-pass filter, and the bus voltage is monitored in real time- for over-voltage protection and power calculation [14]. Figure 11 shows the diagram of the voltage sampling circuit.

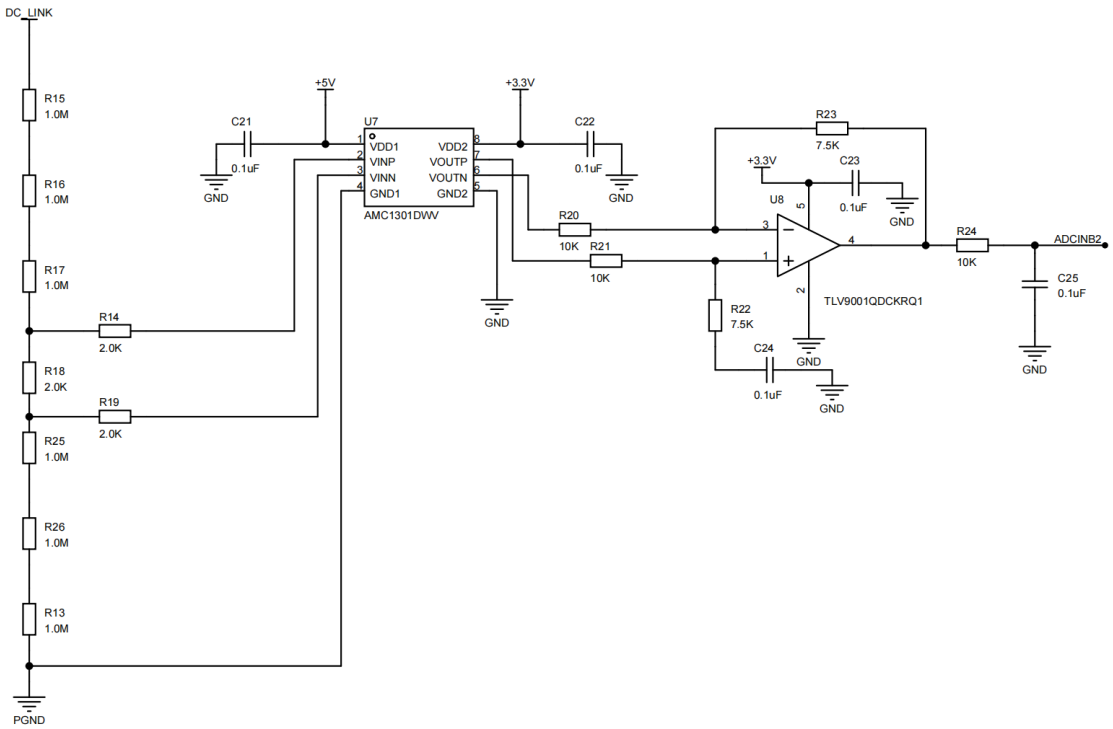


Figure 11. Voltage sampling circuit

3.6. Overcurrent and overvoltage protection circuit

This system has an independent pure analog hardware protection circuit, and does not need to rely on DSP software to determine faults. Once an anomaly occurs, it can cut off the power output within microseconds, providing hardware-level protection for the high-voltage inverter system, and can

DOI: 10.54254/2755-2721/2026.36912

also distinguish and clearly indicate the locked over-current and over-voltage faults. The circuit consists of signal preprocessing, threshold comparison and fault latches with indication [15]. The sampled currents of U and V phases remove DC offset and high-frequency noise by means of RC AC coupling filtering. The filtered signal is amplified by TL0-64, and the instantaneous peak value is obtained- by a peak detection circuit composed of IN5819 Schottky diodes. The LM393 dual voltage comparator separately discriminates faults. The over-current threshold is set by a 3.3V reference resistor voltage divider, and the over-voltage threshold is set- by a voltage divider network matching the bus rated voltage. The rated voltage is 345V, and the peak value is 400V. When exceeding the threshold, the comparator outputs a fault trigger signal, which is shaped by an inverting gate and then enters the 74HC74 flip-flop for latching. The signal is transmitted to the SD pin of the gate driver chip, thereby blocking the PWM signal, turning off the IGBT power stage, and driving the fault indicator to distinguish the fault situation. The circuit does not have a dependence on software, it has a fast response, a reliable protection mechanism, and can avoid the risk of power device burnout [16]. Figure 12 shows the over-current and over-voltage protection circuits.

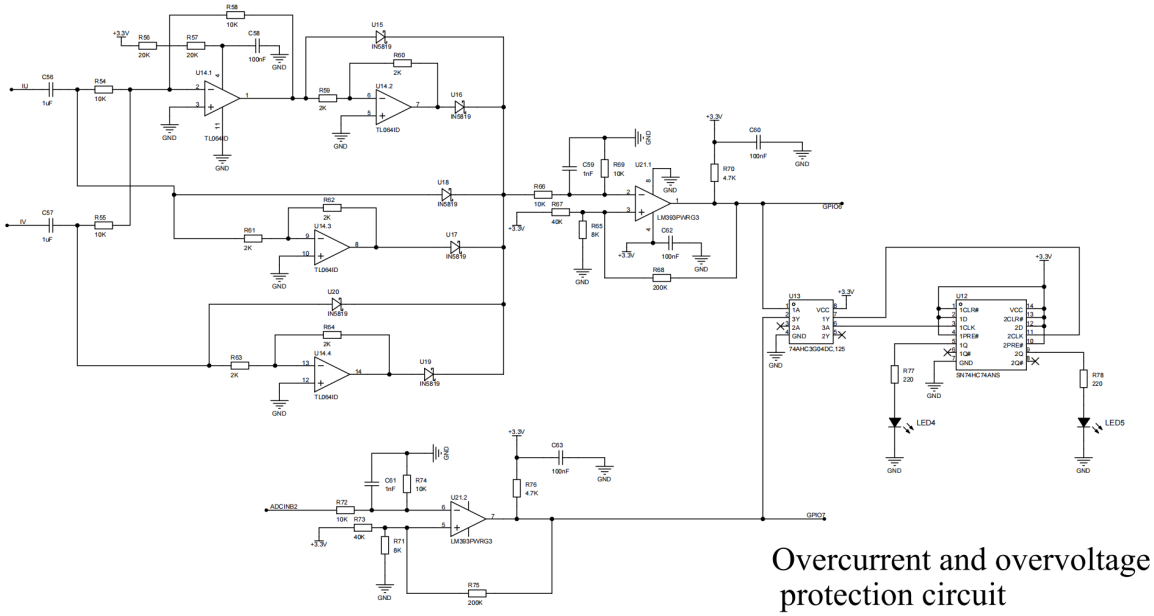


Figure 12. OC and OV protection circuit

3.7. Motor detection circuit

This circuit collects the three-phase Hall position signals of the permanent magnet synchronous motor of the hub motor, and transmits the real-time position of the rotor to the DSP for related operations such as FOC [17]. Three TLE4905 Hall sensors are used as the front-end part, and a PESD5V0V1BL zener diode is connected at the output end for ESD protection. A π-type LC filter (composed of ferrite beads and filter capacitors) is used to eliminate high-frequency electromagnetic noise and optimize the waveform. The Hall signal is connected to a 6N137 high-speed optocoupler, and this optocoupler is connected through a 390Ω current-limiting resistor to achieve electrical isolation between 5V and 3.3V, so as to block common-mode interference and protect the DSP. At the output end of the optocoupler, a pull-up resistor is used with a 3.3V logic level, and a 100nF capacitor is connected in parallel for secondary filtering. The three position signals are connected to GPIO23, 24, and 25 of the DSP [18, 19]. Figure 13 shows the motor detection circuit.

DOI: 10.54254/2755-2721/2026.36912

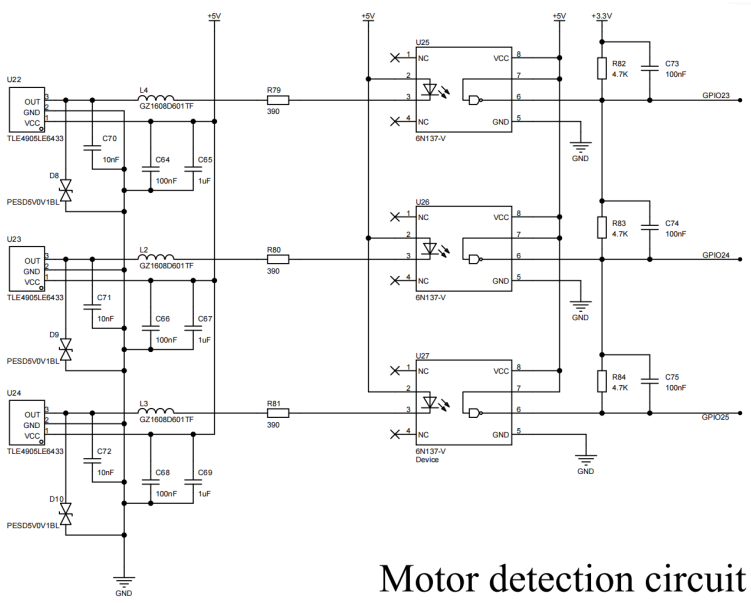


Figure 13. Motor detection circuit

This circuit integrates ESD protection, multi-stage LC filtering and high-speed optocoupler isolation functions, strengthens the stability of vehicle-mounted signal acquisition in harsh electromagnetic environments, resists the interference of high-voltage side noise on rotor position sampling, and ensures the accuracy of vector control and torque adjustment.

3.8. CAN communication circuit

This circuit achieves data interaction between the controller and the vehicle VCU and BMS, transmits transmission rate, current and fault information, and is composed of bus protection, TJA1050 transceiver part and ADUM1201 isolation module. Use P6SMB6.8CA bidirectional TVS diode to handle ESD and surge transient situations of CAN bus input, use 10Ω current limiting resistor combined with 30pF capacitor to form RC filter to remove high-frequency interference, use 120Ω terminal resistor to match bus impedance to reduce signal reflection, TJA1050 implements CAN level conversion, ADUM1201 magnetic isolation chip separates CAN ground and main control digital ground to resist common-mode interference, isolation power supply plus 100nF decoupling capacitor to realize voltage stabilization, communication signal connects GPIO62 and GPIO63 of DSP [20], and Figure 14 shows the CAN communication circuit.

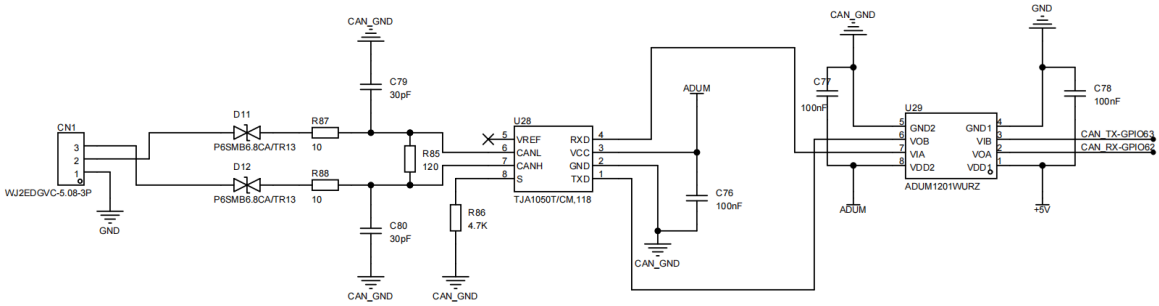


Figure 14. CAN communication circuit

DOI: 10.54254/2755-2721/2026.36912

This circuit has three protections: surge protection, RC filtering and magnetic isolation, which can efficiently isolate electromagnetic noise and the high-voltage side-, make CAN communication more stable in complex vehicle operations and avoid data packet loss and signal distortion.

3.9. Temperature and humidity sampling circuit

This circuit contains the DS18B20 temperature measurement component and the AHT20 temperature and humidity detection component. It collects the temperature and humidity data inside the controller shell and transmits it to the DSP, thus promoting the realization of the overheating and condensation warning function. The DS18B20 uses the one wire protocol. The DQ pin is connected to a 4.7kΩ pull-up resistor to ensure bus communication, and a 100nF filter capacitor is connected in parallel to reduce electromagnetic interference, and the signal is connected to GPIO26 for temperature collection. The AHT20 transmits temperature and humidity information through the I²C bus. The SCL and SDA are connected to 4.7kΩ pull-up resistors to adjust the level. RC filtering is used to improve the signal quality. A decoupling capacitor is added at the power supply to achieve a voltage stabilization effect. The communication pins are connected to the DSP's GPIO28 and GPIO32. Figure 15 shows the relevant situation of the temperature and humidity sampling circuit.

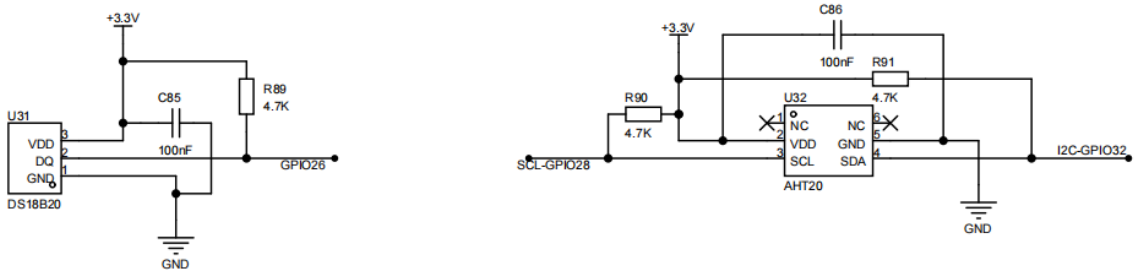


Figure 15. Temperature and Humidity sampling circuit

Combining the 1-wire and I2C communication protocols, the circuit can real-time monitor the electrical control indoor environment. By designing pull-up and filtering, the anti-interference ability is enhanced. It can avoid the situation of short circuit caused by high temperature and condensation in the early stage, and then cause component aging, so as to improve the overall reliability of the controller.

3.10. DSP GPIO allocation

Table 3. DSP GPIO allocation

Type	Pin / Channel Numbers	Hardware Function Definitions	Key Components	Circuit Module
GPIO	GPIO00,GPIO01,GPIO02,GPIO03, GPIO04,GPIO05	PWM outputs (3-phase, high/low side)	IR2110,IKW75N65EH5 IGBT	3-phase inverter
GPIO	GPIO23,GPIO24,GPIO25	3-phase Hall position acquisition	TLE4905,6N137	Rotor position detection

DOI: 10.54254/2755-2721/2026.36912

Table 3. (continued)

GPIO	GPIO26	DS18B20 temp. (1-wire)	DS18B20	T&H sampling
GPIO	GPIO28	I2C clock SCL (AHT20)	AHT20	T&H sampling
GPIO	GPIO32	I2C data SDA(AHT20)	AHT20	T&H sampling
GPIO	GPIO62	CAN RX	TJA1050,ADUM1201	CAN circuit
GPIO	GPIO63	CAN TX	TJA1050,ADUM1201	CAN circuit
GPIO	GPIO06,GPIO07	Fault latch input (OC/OV)	TL064,LM393,74HC74	Protection circuit
ADC	ADCINA2	U-phase current	ACS772,RC	Phase current sampling
ADC	ADCINA3	V-phase current	ACS772,RC	Phase current sampling
ADC	ADCINA4	DC bus current	ACS772,EMI	Bus current sampling
ADC	ADCINB2	DC bus voltage	AMC1301,TLV9001	Bus voltage sampling

4. Research limitations and future prospects

The hardware circuit schematic design, component selection, and PCB(Figure 16)layout partitioning and routing for the hub motor controller have been completed. However, we have not fabricated the PCB, soldered and assembled the components, or produced a physical prototype. Additionally, we have not set up a high-voltage motor test bench or conducted physical vehicle tests, which are clear limitations. The performance of all power drive, isolation sampling, hardware protection, and CAN communication modules is supported only by theoretical analysis and routing scheme simulations. There is a lack of measured data regarding sampling accuracy, fault protection response speed, and electromagnetic immunity. The DSP-based field-oriented control (FOC) algorithm has not been integrated and debugged with the hardware system. Moreover, we have not performed reliability verifications under harsh automotive environments such as extreme temperatures, vibration, and condensation. As a result, we cannot identify practical engineering issues like strong/weak current coupling interference from PCB routing, power trace voltage drops, or component thermal drift. Consequently, the actual operational performance of the overall hardware design cannot be substantiated.In future work, we will fabricate physical prototypes based on the completed PCB drawings. We will build a 345 V high-voltage hub motor back-to-back test platform to quantitatively

DOI: 10.54254/2755-2721/2026.36912

calibrate the actual performance metrics of each hardware module. The FOC vector control algorithm will be ported to the DSP to enable hardware-software co-debugging. We will simulate driving conditions such as climbing, hard acceleration, and regenerative braking to optimize the parameters of filtering and isolation circuits. Simultaneously, we will conduct reliability tests including damp heat, high/low temperature, and vibration endurance. Finally, we will mount the controller on a vehicle for road testing and iterate the hardware design accordingly. Furthermore, we can extend the system with multiple drive and sampling channels to build a four-wheel hub motor coordinated control hardware platform.

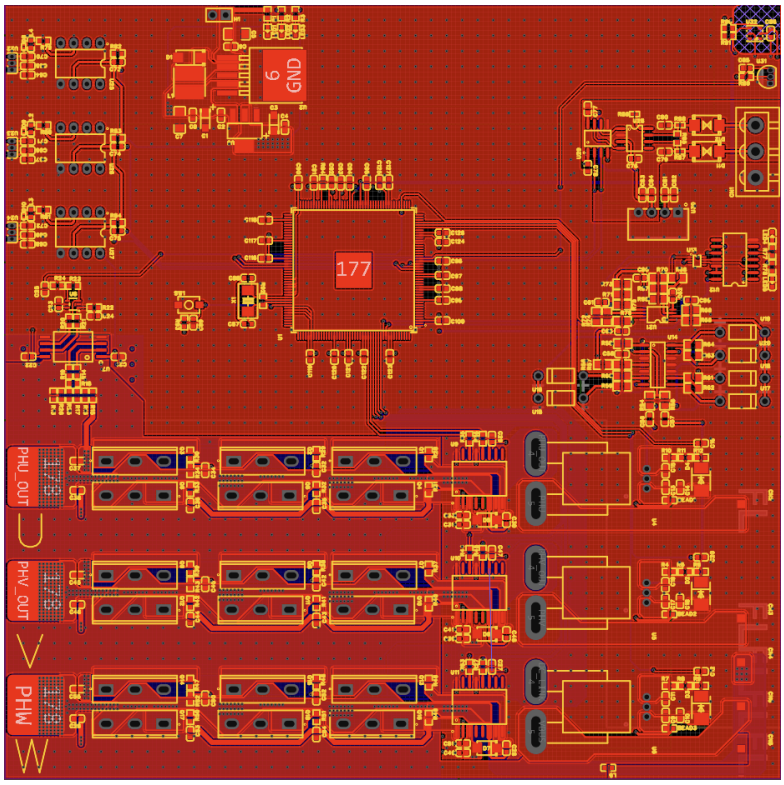


Figure 16. PCB of the circuit

5. Conclusion

This article presents the hardware system design of a 345V high-voltage permanent magnet synchronous hub motor drive controller based on the TMS320F28379D dual-core digital signal processor, which is applied in vehicle scenarios. It reviews the research and development and industrialization status of hub motors and related electric controls at home and abroad, compares the application scenario differences of induction, brushless DC, permanent magnet synchronous motors and direct, gear reduction drives, and thus determines to take the permanent magnet synchronous hub motor as the control object. To cope with the situations of poor adaptability of domestic electric control hardware in high voltage and heavy load, lack of independent hardware fault safety protection and weak electromagnetic interference resistance, a modular approach is adopted to carry out the development of the hardware circuit, which includes seven key modules: multi-level power conversion, three-phase two-level power inverter, multi-isolation current and voltage sampling, pure analog hardware over-current and over-voltage protection, Hall rotor position detection, isolated CAN bus communication, and electronic control room temperature and humidity monitoring.

DOI: 10.54254/2755-2721/2026.36912

The hardware circuit design has three prominent advantages: having multi-layer electrical isolation characteristics, having multi-level EMC noise reduction means, and having a hardware fault self-locking protection mechanism. The independent analog protection circuit can interrupt the power supply level at the microsecond level, avoiding the situation that the main controller program crashes and causing the device to be burned. All signals have isolation and filtering functions, and can adapt to the vehicle-mounted usage environment with high voltage, large current, and strong electromagnetic interference. The hardware facilities can stably support the FOC vector control and SVPWM modulation algorithms to meet the needs of heavy-duty vehicles under complex working conditions. This design can provide a comprehensive engineering reference for the hardware development of the high-voltage hub motor controller.

References

[1] Yu, Y. C. (2026). In 2025, China's automobile production and sales hit a record high. Heading into 2026, the industry faces both transformation and challenges. *Automotive Technician*, (3), 21–22+27. (in Chinese)

[2] Zheng, X. Q. (2026). Sales of domestically produced new energy vehicles reached 16.49 million units in 2025. *Auto Review*, (2), 110–111. (in Chinese)

[3] Zhang, Y. W. (2026, April 13). New energy products gain volume, overseas business profits surge. *China Automotive News*, (018). (in Chinese)

[4] S. S. T. K. S. S. T. Y., & H. Y. (2024). Autonomous distributed braking and driving force control architecture based on broadcast control for vehicles with in-wheel motors on four wheels. *Vehicle System Dynamics, 62*(12), 3108–3132.

[5] Deepak, K., Frikha, M. A., Benômar, Y., El Baghdadi, M., & Hegazy, O. (2023). In-wheel motor drive systems for electric vehicles: State of the art, challenges, and future trends. *Energies, 16*(7), 3121.

[6] Han, Y. Q. (2024). Research on electromagnetic force characteristics and vibration and noise of outer-rotor permanent magnet in-wheel motors [Doctoral dissertation]. Harbin University of Science and Technology. (in Chinese)

[7] Yang, J. Q. (2023). Research on in-wheel motor design and its steering stability control strategy for distributed electric tractors [Doctoral dissertation]. Nanjing Agricultural University. (in Chinese)

[8] Yin, J. X., & Ma, J. H. (2021). Application of TMS320F28379D in dual-motor synchronous control. *Light Industry Machinery, 39*(4), 56-61+67. (in Chinese)

[9] Velmurugan, D., Lin, C. K., Arumugam, A., et al. (2026). Gradient descent-based model predictive current controller for dual three-phase PMSMs. *IET Power Electronics*.

[10] Pillay, R., Ameen, S. S. M., & Mohd, M. N. I. (2025). Enhanced current balancing between parallel Si IGBTs and SiC MOSFET by co-switching in high-power inverters. In *2025 IEEE 21st International Conference on Power Electronics and Drive Systems (PEDS)*. IEEE.

[11] Jin, Z., Wang, J. Y., & Xu, W. (2026). Research on interaction analysis and modeling method between permanent magnet synchronous motor and DC bus disturbance. *Transactions of China Electrotechnical Society, 1*–14. (in Chinese)

[12] Ren, D. H. (2018). *Design and development of an integrated power supply with DC-DC and DC-AC converters for electric vehicles based on DSP* [Doctoral dissertation]. Inner Mongolia University of Technology. (in Chinese)

[13] Cheng, G. (2025). *Research on phase current reconstruction technology for permanent magnet synchronous motor based on resistor sampling* [Doctoral dissertation]. Beijing Jiaotong University. (in Chinese)

[14] Zhang, L., Lu, Q. Z., Maerdan Tuerxun, et al. (2026). Research on fault diagnosis technology for high-voltage systems in new energy vehicles. *World Automobile*, (5), 44–45. (in Chinese)

[15] Li, C., & Pan, S. F. (2019). Hardware design of permanent magnet synchronous motor control system based on DSP. *Manufacturing Automation, 41*(9), 118–120. (in Chinese)

[16] Wang, Z., et al. (2021). A transferrable data-driven method for IGBT open-circuit fault diagnosis in three-phase inverters. *IEEE Transactions on Power Electronics, 36*(12), 13856–13869.

[17] Wang, J. S., Zheng, S. C., Yu, C. Z., et al. (2021). Circuit design of drive motor control system for electric vehicles. *Journal of Jiamusi University (Natural Science Edition), 39*(3), 133–136+149. (in Chinese)

[18] Zou, C. Y. (2024). *Design of control circuit for single-phase brushless DC motor with integrated Hall sensor* [Doctoral dissertation]. Xidian University. (in Chinese)

DOI: 10.54254/2755-2721/2026.36912

[19] Cheng, X. D. (2024). *Research on rotor position detection of outer-rotor permanent magnet synchronous motor based on linear Hall* [Doctoral dissertation]. Chongqing University. (in Chinese)
[20] Peng, M. Y., Lü, J. L., Cao, D., et al. (2020). Structural design of automotive EMB based on CAN bus. *Science and Technology Innovation Herald, 17*(8), 31–32. (in Chinese)