

Research on the Technical Path for Efficient Integration of Power Electronic Control Systems in New Energy Vehicles

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Abstract: Fast growth in the NEV sector has pushed EV to a more effective level of integration, because it has a direct effect on the energy use, performance, and operating stability of the car. In this article, we will study the design of a novel EV electric control system, which will address the present problems of structure redundant, power dissipation, and insufficient adaptive capability of the system. It discusses the technological principles of effective integration by means of hardware, circuitry, and software compatibility, as well as an approach to implement mass production. The results can be used to improve the EV's overall performance and to promote the development of EV.

Keywords: New energy vehicles; Power electronic control; System integration; Technical approach

Online publication: Jun 29, 2026

1. Introduction

The EMS is the central point of NEF and EV, and its integration and efficiency is one of the main trends of industrial technology. The disadvantages of conventional distributed electronic control structures are too big, too much power to be used, and they are not compatible with the requirements of a new type of power car: light weight, long distance and high reliability. Owing to the constant innovation in the field of power electronics, chip architecture, and onboard control techniques, the realization of an effective integration of the ECU is a key issue in the field of automotive engineering.

2. Integrated development fundamental principles of new energy vehicles for power electronic control systems

2.1. Power electronic control system's core components and operating mechanism

The main components of the electric control system are the electric motor controller, the battery managing section, the on-board charger and the DC-DC converter. While working in coordination with one another,

each of the modules has a well-defined functionality that can be used to support the whole vehicle's power distribution and energy flow. Utilizing established power-electronic transformation principles, the system adjusts the voltage, transforms the frequency, and makes smart distribution of the electric energy from the cell so that the driver can operate accurately and stably. It keeps track of real time parameters, from voltage, current, temperature, and residual capacity, and makes a scientific adjustment of the charging and discharging arithmetic so that it can be operated safely in a variety of running situations, for example, starting, accelerating, steady, and decelerating.

The whole system follows a closed-loop operation logic that includes the collection of signals, logic processing, and command execution. By means of a car bus, high-speed data interchange is realized between the modules, so that key operational parameters, including the opening of the throttle, the velocity of the car, the level of the cell, and the total load of the vehicle are monitored in real time, so that the control strategy can be quickly computed and implemented. The level of interoperability between key parts decides the performance of an automobile, its energy-consuming, and its ride comfort, which is an essential precondition for developing an effective system integration technique and designing an optimum system solution.

2.2. Efficient system integration technical requirements and performance metrics

NEU sets out a set of clear and strict specifications for the effective integration of EV systems, with a primary emphasis on miniaturizing and reducing weight. Deep integration of multifunction modules will keep the total system space to a minimum, which will significantly lower the curb weight of a car and increase its range and maneuverability indirectly. At the same time, there is widespread demand from the industry for a steady, low-power operation, which reduces the amount of electricity lost as a result of the total energy savings and low carbon emissions, a promise which is in line with the key goals and industrial trends of NEV.

As far as performance measures are concerned, a high-performance integration design has to satisfy three key criteria: high reliability, powerful EMI capability, and fast dynamic response. Once integrated into the system, they shall be able to function in complicated on-board situations characterised by high temperatures, moisture, uneven surfaces and strong vibrations, whilst at the same time preserving the long term stability and continuity of service; effective mitigation of inter-interference between inner loop signals to assure accurate delivery of all control orders; substantially decrease the delay in the control response to obtain instant and precise power output matching, thus meeting the double high level demands of everyday and 24-hour operation security^[1].

2.3. Electronic control system integration technology: Current status and evolution trends

At present, the power train control systems in China are mainly based on the discrete modular combination. The independent development of each of the control units has its own configuration, which leads to a complicated and long outer circuit cord between the modules. Not only does this take up a considerable amount of space in the cab and chassis of the car, it is also easy to cause EMI and other energy transfer losses. While a number of high-end models use a combination of two or three in one, the whole is still very shallow. There are still major weaknesses in the architecture standardisation, the universality of the model, and the deep compatibility of the functionality, which suggests that there is considerable scope for further

development in the field of core integration.

The development of ECCS in the future will be based on 3 main tendencies: highly integrated, hardware and software integrated, and platform based standardization. This method will move away from simply combining several modules physically into a deeply integrated inner circuitry and architecture, enabling an integrated package of power components, control chips, and drive circuitry. A synchronous, cooperative optimized design pattern will be used in both hardware and software, which is different from the conventional fragmentation. At the same time, it is possible to build a standard integrated technical platform that can accommodate various types of cars and power levels, which can efficiently cut down on research and development and large scale manufacturing costs, as well as to satisfy the diversified requirements of the NEV industry.

3. Addressing the existing core technology gaps in power electronic control system integration

3.1. Insufficient redundancy and spatial adaptability in hardware module layout

Conventional EMC hardware generally uses a discrete, separate design method, with every function module having its own protection shell and special installation structure. The design allows for too many unwanted mounting gaps and redundancy of the cooling space among the modules, which leads to a slack, redundancy of the layout and poor spatial efficiency. This traditional arrangement takes up considerable precious mounting space in the motor cabin and the chassis, which impedes the overall optimal design of the chassis and the reasonable location of the high-capacity battery assemblies. As a result, it does not satisfy the actual needs of compact space configurations of compact cars as well as dedicated new power utility cars.

Owing to the lack of a single industry design standard for the manufacture of hardware modules, there are significant variations in external dimensions, mounting dimensions, and electrical interface parameters among different manufacturers. This makes it impossible to standardize the assembling and replacement of the components, which greatly increases the complexity of the initial design and the subsequent modification of the car. Moreover, the distributed arrangement leads to distributed and chaotic heat-dissipating pathways for the power cells, which is harmful to the cooling efficiency of high-heat-generating parts. This is one of the drawbacks of the system when it runs at a very high load for a prolonged time, which directly affects the normal running and long-term life of the electric control system.

3.2. Disturbance of high loop signal and power transfer loss

The DIS consists of a number of functional modules, with long and messy exterior wiring harness layout. The high voltage wire and the control signal wire are arranged in the interlace and parallel arrangement, so that the electromagnetic coupling and cross talk are easily generated. This leads to the distortion of the wave shape and the transfer delay in the weak control signal, which is a direct threat to the accuracy of the coordination control and the reaction synchronization. In addition, the electromagnetic radiation produced when the high frequency electric circuit is operated has an indirect effect on the normal operation of low voltage systems (car navigation, communication and audio/visual entertainment), so that the whole reliability of the electric and electric system of the car is decreased.

Long outer wiring cords and excessively long middle connecting terminals greatly add to circuit contact resistance and transmission losses, resulting in extra wasted energy in the process of transmitting power from

a cell to a drive motor, and a further reduction in the total energy use efficiency of a vehicle. In addition, an additional wire connection significantly increases the probability of failure of wiring, oxidation, bad contact, short-circuit, and leak current, resulting in an increase in maintenance and repair workload, as well as operating expenses, and seriously hampering the integration and miniaturisation of an electronic control system.

3.3. Lack of cooperation and compatibility between multiple controllers

At present, the control software that accompanies each of the electrical control modules is mainly independent development by a variety of vendors, using differential programming structures, on-board communication protocols, and internal control logic policies, but there is no uniform design criteria and interfaces for cooperative integration. Every controller is only concerned with the specific function of the system, and does not deal with the interchange of data between the modules or the coordination of the control between the different types of operation ^[2]. This usually results in major problems in complicated operating situations like accelerating/decelerating the car, recovering power, or changing the driving pattern, which may involve a clash of control logic and an asynchronous response.

There is a shortage of industry standard in automobile bus communication protocols. Due to the inconsistency of the data coding format, the speed of the signal and the validation of the validation rules, the various software systems cause the delay and the occasional loss of the packet, which impedes the real-time, accurate coordination of the various controllers. Moreover, there is a lack of a comprehensive coordinating mechanism in the software system update; every function module needs a separate blinking and debugging procedure. Not only does this lower operation efficiency, but it also adds to the safety hazards like incompatible software releases and system crashes, thus hindering the long term development of a comprehensive and uniform EMS management.

4. Key technical dimensions for the efficient integration of power electronic control systems

4.1. Power devices modular integrated architecture design technology

Module integrated architecture for power components is a key component to realize an effective integration of electrical control system. Using high performance power devices with broad band gap (e.g., IGBTs and SiC), it combines switching power, driver controller, and over-current/over-over-voltage protective circuitry into one package, which has totally superseded the obsolete design method of assembling separate parts. By simulating the path optimization of the inner circuitry and the compact arrangement of the equipment, the total dimensions of the power cell are greatly reduced, and the complicated outer wiring is simplified, allowing for a high-standard design, which is characterised by small and integrated features.

The module structure follows the standard pin definition and the uniform installation interface design, and has the same machine size and electric properties. This makes it possible to quickly adapt to the installation needs of the ECU in different models. The combination of a scientific optimal heat-dissipating contact surface arrangement and a uniform, highly efficient heat-dissipating base material can greatly increase the effectiveness of the system's continuous cooling and effective reduction of operating losses at high temperature and high load. This integrated method ensures long term stability and reliability of the EMS in high stress conditions.

4.2. Electromagnetic compatibility optimization technology and high-density circuit layout

High density IC layout makes use of multilayered PCB stack design procedures and compact parts placement skills to efficiently integrate high power circuitry, core control circuitry, and low power signal circuitry in a restricted panel space, thereby substantially decreasing the total size and size of an electronics controller mainboard. The technique uses special EM simulation software to optimise circuitry route, linewidth, gap and loop layout to efficiently reduce the RF signal's parallel coupling disturbance and to minimise the EMI hazard at the source of the circuitry.

The EMC is based on integrated technology, which consists of a partition of physical isolation, an optimal earthing circuit, and an embedded filter at the input end. Physical separation of high power operation zone from high power low power level is achieved by these measures, and a special earthing circuit is effective in decreasing common mode interference. Proper filtration elements are arranged in the input and output terminals of the circuitry to inhibit the transmission of high frequency harmonic and space radiation^[3]. In addition, the optimum shielding and sealing structure of the metallic housing avoids the interaction of electromagnetic signals from inside and outside of the apparatus, thus guaranteeing the continued and steady functioning of the electrical control system in complicated on-board electromagnetic conditions.

4.3. Integrated development technology and hierarchical control software architecture

Based on this framework, the whole ECU software structure is classified into 3 levels, which are lower drive level, middle adaptive level, and applied strategy level, which realizes the complete separation of software from hardware, and module of system functionality. The lower level of drive is mainly connected to the primary controller's hardware circuitry and its peripheral resources, and the middle adaptive level regulates the communication agreement of the car and the standardized data interface, and the application strategy level emphasizes the realization of the key service functions, including the power control, the smart power management and the smart failure diagnosis. This well-defined architecture level makes it easier to repeat, update, and optimize later.

Through the adoption of the uniform and standardization industrial standard of the automobile bus, the standardization of the data exchange rules and the signal defining protocols of the multi-controllers were set up to overcome the technological obstacles among the various vendors, so that the data can be integrated seamlessly and the real-time can be shared at high speed. Based on the MFD technique, a general and portable control arithmetic model has been developed, which can be adapted quickly to different kinds of hardware integration structures and real vehicle operation. In addition, a comprehensive software update and failure diagnostic platform has been developed to enable multi-controllers to be updated simultaneously, as well as a single smart failure detecting system, thus greatly improving the overall functionality of the software collaboration.

5. Efficient integration implementation path between new energy vehicles and electronic control systems

5.1. Optimized integrated hardware architecture design

In order to meet the double demands of a light weight car and a compact interior, an integrated structure has been carefully devised for electric control, battery management, and DC-DC converters. Using an innovative

design method that includes a common protection cover, a common circulation cooling duct and a prebuilt inner cable cord, the removal of superfluous outer connections and individual shell parts, thus decreasing the total size and weight of the structure. Based on the actual size of the car cab, these components are optimized for design and construction so as to make sure that they are perfectly aligned and seamlessly integrated into the whole body of the car.

The establishment of an overall standardized software package for component integration should cover assembly interfaces, connector terminals, and heat management protocols, thereby enabling the development of a standardized VMI platform compatible with NEV models featuring different ranges and performance levels. At the same time, structural strength and in-vehicle vibration simulation studies should be conducted to optimize the selection of shell materials and internal reinforcing structures. These measures can substantially improve the integrated modules' resistance to impact, vibration, and aging under extreme temperature conditions, while fully meeting the requirements for long-term reliability in complex onboard operating environments.

5.2. Establishment of a low-loss transmission optimization system for electromagnetic compatibility

A standardized EMC framework should be established to create a strict control system covering the entire process, including hardware configuration, circuit routing, shielding structures, and system grounding. EMC design requirements should be integrated at the early stage of integrated system design to avoid increased costs and performance degradation caused by later modifications and optimization measures. In addition, specialized shielding cables and anti-interference filter connections should be adopted in place of conventional external wiring to effectively reduce EMI and signal transmission distortion over long distances, thereby improving the reliability and accuracy of circuit signal transmission ^[4].

Optimization of the whole route planning and design of vehicle power transfer is carried out through reasonable reduction of key electrical track marks and use low resistance, high performance electrical conductivity for connection and end, so as to minimise the internal energy loss caused by the production of heat. Scientific matching of the terminal's specifications with the current load capability will result in effective reduction of the contact resistance and the operating heat loss. At the same time, the smart energy allocation policy is improved so that the efficiency of the PV system can be accurately adjusted between the function modules, thereby minimising the amount of unwanted energy wastage. All of these improvements improve the overall power transfer efficiency by means of the hardware structure and the smart control mechanism.

5.3. Establishment of an adaptation mechanism for multi-module software collaborative regulation

Industrial standards for the CSRS and VCS should be established by developing integrated data exchange criteria for multi-controller systems, together with operational rules for the coordination of cross-modular control logic. Such measures can eliminate technological barriers and compatibility issues among different vendors. In addition, the development of a comprehensive vehicle-wide cooperative control platform should be promoted to coordinate the operational logic and control strategies of modules related to the battery system, motor system, and power generation system, thereby ensuring synchronous responses and accurate,

efficient coordination among all modules during state transitions and dynamic load distribution.

A rapid adaptability and dynamic parameter calibration system should also be established to support both integrated circuit design and real vehicle operation. Furthermore, an integrated cloud computing platform should be developed to enable the remote synchronized online updating of multiple electronic control modules, intelligent online fault diagnosis, and the self-tuning and optimization of control parameters. These measures can continuously improve the overall performance of the cooperative control system, thereby providing a strong foundation for the long-term stable deployment and large-scale application of efficient integrated control technologies.

6. Conclusion

Integration of EPS into the NEV is one of the necessary developments in the industry and is the key to improving the range, performance, and security of the car. In this article, we look back on the development base and technological limits of EMC, and define critical integrated techniques for EMC, EMC and SDI, and set up a systemic implementation plan covering structure, transfer, and software. Achieving an effective integration of EMC is an effective way to solve the problems related to conventional discrete structures, including space redundant, power dissipation, and lack of coordination. It helps to miniaturize, reduce power consumption, and increase reliability of electrical control elements. It also gives a practical direction to develop and commercialize key electronics in NEV and propel the sector towards smart and comprehensive solutions.

Disclosure statement

The authors declare no conflict of interest.

References

- [1] Ding W, 2023, Application of Electronic Diagnostic Technology in the Maintenance of New Energy Vehicles. *Electronic Technology*, 52(2): 208–209.
- [2] Xie C, 2024, Optimization Analysis of Electronic Control Systems for New Energy Vehicles. *China High-Tech*, 2024(9): 23–25.
- [3] Hong K, Li L, Fan X, et al., 2025, Research on Cloud-Based Real-Time Monitoring and Control Technology for Electronic Information Management Systems in Intelligent Connected New Energy Vehicles, Guangxi Cybersecurity and Informatization Federation. *Proceedings of the 12th Academic Conference on Engineering Technology Management and Digital Transformation*, 467–471.
- [4] Lu X, 2026, Fault Diagnosis and Maintenance of Electronic Control Systems in New Energy Vehicles. *Automotive Maintenance Technician*, 2026(2): 35–36.

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