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A Review of Hybrid Technology Applications and Development Trends

Jiayi Li[1, a]

[1]Foshan No.1 High School, Foshan, 528099, China
[a]rylxisvnuchrke@gmail.com

Abstract: Currently, fossil fuel combustion and carbon emissions are triggering an increasingly serious greenhouse effect, which, coupled with the energy crisis, requires the transformation and upgrading of power modes for vehicles, transportation and engineering instruments. Due to the limitations of batteries in terms of energy density and range, pure electric drive cannot well meet the daily driving needs. The central idea of hybrid power is to make the internal combustion engine (ICE) and electric motor (EM) work together to improve energy utilization, energy saving and at the same time solving the problem of short range of electric vehicles. Vehicles and instruments utilizing hybrid powertrains have low emissions, low fuel consumption levels, high fuel economy, and energy recovery at the same time. This paper provides an overview of the structure and energy forms of hybrid technology and their applications, design simulations done by previous authors, optimization strategies, and summarizes the future trends of hybrid technology.

Keywords: Hybrid Technology, Powertrain Configurations, Control Strategy Optimizations.

1. Introduction

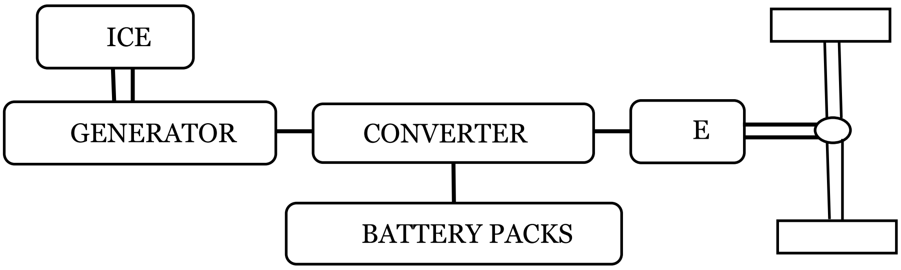
Hybrid technology has become the focus of research and development of domestic and foreign automobile city and hot spots, it is a technology that uses two different power sources in the power system, according to the structure of the power drive configuration relationship is divided into series, parallel and hybrid, according to the proportion of the motor output power is divided into light hybrid, medium hybrid and heavy hybrid. Different forms of energy are hydrogen, hydraulic, oil, gas and electricity, etc. Hybrid can be divided into Plug-in Hybrid Electrical Vehicle(PHEV) and Hybrid Electrical Vehicle(HEV) according to whether charging is required. Hybrid vehicles combine the advantages of both fuel-electric vehicles and pure electric vehicles. Not only do they have strong economy, power and emissions, but they are also less expensive than pure electric vehicles.‹

The world's first hybrid car was the 1896 Armstrong Phaeton prototype, and the earliest mass-produced hybrid model was the 1997 Toyota Prius. Ferdinand Porsche's gasoline-electric car, the Semper Vivus, was shown at the 1900 Paris Exposition and could travel nearly 40 miles on electricity alone. in 1914, the Galt Motor Company of Canada marketed a series of hybrid cars with small gasoline engines that were used to drive generators to produce electricity [1]. This car was claimed to have a fuel consumption of 4 liters per 100 km, which was lower than the current Toyota Prius. Due to cost, the hybrid concept's faded during World War I and was not taken seriously again until the early 1970's. In 1975, the U.S. Energy Research and Development Administration (erda) initiated a government program to advance electric and hybrid vehicle technology. Since the late 1990s, Toyota, Audi, Honda, Ford and others have launched hybrid vehicles. Today, there are also mainstream hybrid brands such as Buick, BYD and BMW.

Hitachi Construction Machinery launched the world's first hybrid wheel loader in 2003, opening up the market for the application of hybrid technology in construction machinery [2]. In 2010, China's first hybrid loader, the CLG862-HYBRID, was launched by LiuGong Group. Hybrid applications also include unmanned aerial vehicles and construction equipment, which may be used in more diverse fields in the future. An overview of the applications and optimization strategies of the technology will serve as a guide for the future direction of the technology.

2. Basic Structural Forms of Hybrid Technology

2.1. Series Hybrid Electrical Vehicle (SHEV)



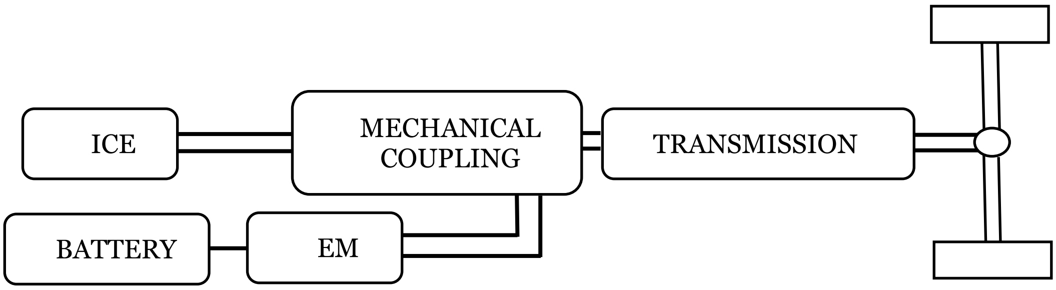
Mechanical Connection =，Electrical Connection —
Figure 1. Series hybrid electrical vehicles

It consists of three major power assemblies: engine, generator and drive motor, which are connected in series to form a drive system. Its power comes from the electric motor, pure electric drive, fuel engine drive generator for battery charging, can not directly drive the vehicle traveling. This mode is mostly used in large vehicles, such as heavy-duty vehicles, military vehicles, and buses. Applications that utilize series hybrid configurations include the Tesla Ultra Light Rail, Honda i-MMD system, Chevrolet VOLT, etc.

Among them, series plug-in hybrid, also known as add- on hybrid, can be applied to medium and large-sized UAVs, which can still use pure electric drive in short-range voyages, with lower fuel consumption and cost, which reduces the use and maintenance cost of UAVs. Zhu Yingtao et al. modeled and designed the energy system and thrust system of a tandem hybrid UAV, showing that the range of a hybrid UAV is better than that of a traditional purely electrically powered UAV [3]. The tandem hybrid tractor Belarus-3023 utilizes an electromechanical drive train (EMD) to reduce fuel consumption by 18% and increase efficiency by 3% [4]. Liu Yaqian et al. designed an extended range hybrid forklift that successfully realized three different operation modes for use under different working conditions: extended range, electric and composite drive modes [5]. In 2019, a tractor manufactured by FPT Industrial and STEYR used a tandem hybrid, where a 4-cylinder diesel engine and 4 hub motors cooperated with a NEF45 engine to save 10% of fuel under specific operating conditions [6].

The advantage of series connection is that it has a simple control system and less emission, but the energy conversion is frequent and the mechanical efficiency is not high.

2.2. Parallel Hybrid Electrical Vehicle (PHEV)



Mechanical Connection =, Electrical Connection —

Figure 2. Parallel hybrid electrical vehicles

A parallel hybrid system uses both an electric motor and an engine to drive the wheels, either jointly or independently. The basic structure consists of an electric motor, engine, HV battery, transformer and transmission. The system utilizes the power from the HV battery to drive the electric motor. Since the electric motor doubles as a generator, it cannot be used for driving while generating electricity. When single motors are connected in parallel, they are categorized as P0,P1,P2,P3,P4 according to the relative positions of the motors. Parallel structure has a large self-weight and is suitable for pickup trucks heavy trucks and buses. The representative models are BYD Qin, Honda Insight, Lexus hybrid SUV, and F1 racing car also adopts parallel hybrid system. In addition, there are some data and experimental results of parallel hybrid models, such as Kang Guiwen et al designed a power system for the Canadian DA20-C1 two-seater aircraft, and the simulation results show that the performance of the parallel hybrid system aircraft is better than that of the ordinary fuel aircraft, which provides a theoretical basis for the parallel hybrid aircraft manufacturing [7]. The new parallel hydraulic hybrid system for hydro-mechanical loaders proposed by Li Luxing et al. realizes energy recovery and reuse, and improves fuel economy by 18% [8]. Shandong University of Technology proposed a single-axle parallel hybrid forklift, and simulation experiments showed that the new forklift saves 12.57% in fuel and improves the hauling limit by 12.45% compared to the traditional hydraulic forklift with internal combustion engine [9]. Gong Jun et al designed the energy recovery and drive system of parallel hybrid forklift, and the experimental results illustrate that the hybrid forklift saves nearly 21% energy [10]. These studies provide important theoretical support and practical basis for the development of parallel hybrid models.

The advantage of the parallel type is that it is more fuel economical and has improved efficiency, but the structural layout is complicated.

2.3. Parallel-Series Hybrid Electrical Vehicles (PSHEV)

It consists of three power assemblies: engine, electric motor and drive motor, and is categorized into power-split structure and series-parallel structure according to the position of the engine. Works in four modes: pure electric mode, series mode, parallel mode and direct engine drive mode. The electric motor drive system and the internal combustion engine system are each equipped with a mechanical gearshift mechanism, which is connected together to regulate the speed through a power splitter (PSD). The representative model is Toyota Prius, and is mostly used foe large drones/airplanes. Kang Jianjian designed the power coupling system of the parallel-series hybrid tractor based on the transmission characteristics and operating conditions of the tractor. The overall analysis is carried out from the layout and design of the transmission, the structural selection of the hybrid power system, and the performance usage analysis is completed from the two parts of economic performance and traction performance [11].Guilin et al. conducted simulation experiments using MATLAB and AMESim to analyze the suspension system electro- hydraulic composite control, power steering system, and braking system of the parallel-series hybrid vehicle, and the test results show that under the electro-hydraulic composite control of the parallel-series hybrid vehicle, there are certain fluctuations in the steering torque and hydraulic system pressure in the steering system, and in the braking force and speed in the braking system. The test lays a theoretical foundation for the design and analysis of the electro-hydraulic composite control system of hybrid vehicles [12].

The parallel-series hybrid structure has the advantages of excellent energy distribution, high efficiency, good energy saving effect, flexible control, and comprehensive ability to be the best of the three main mixing methods. However, the structure is relatively complex, and the cost and quality are large.

3. Energy Forms for Hybrid Technology

3.1. Electric-hybrid

It adopts both electric power and fuel drive, which solves the problems of insufficient range of pure electric power and excessive pollution of pure fuel. Used in ferries, law enforcement vessels, research vessels, etc., combining the advantages of both diesel and electric motors, easy to maneuver, sufficient power, cost-effective, MAN, Rolls-Royce, Wärtsilä and other companies already have diesel-electric hybrid solutions for ships. Diesel-electric hybrid drones increase range and load, and can be used for large-scale agricultural activities such as pesticide spraying, as well as transportation of supplies and other tasks. Sany Heavy Industry SY215, Zhejiang University ZE205E-hybrid oil-electric hybrid excavator saves about 30% energy [13].

3.2. Hydraulic hybrid

Using an accumulator as the energy storage element, a high-pressure liquid is used instead of an electric current to convert pressure energy into kinetic energy. Compared to batteries, accumulators have the advantage of recovering braking energy, and are therefore widely used in commercial vehicles due to their excellent energy recovery and fuel-saving capabilities. For short driving cycles, commonly found in garbage trucks, the use of a Hydrostatic Regenerative Brake System (HRB) can save up to 30% of fuel! [14] In Japan, a self-developed Constant Pressure System (CPS) has been applied to buses, and has been tested in real-world applications, resulting in fuel economy improvements of around 20% [15]. A regenerative drive system (RDS) was applied to the FMTV M1084 A1 Army Tactical Vehicle to increase the braking rate to 160% of the original [16]. Sun Hui designed a parallel hydraulic hybrid drive system for energy saving in loaders with frequent start-stop operation, which can reuse the energy lost due to braking in traditional loaders, reduce the fuel consumption of the loader, and improve the work performance [17]. The hydraulic hybrid technology is mainly Eaton. This field is mainly being invested in research by companies such as Eaton, Permo-Drive and Mitsubishi.

3.3. Hydrogen-electric hybrids

Hydrogen-electric hybrid systems are an expansion of traditional plug-in hybrids. Fuel cell (FC) engine system will be hydrogen and oxygen through a chemical reaction to convert chemical energy into electrical energy for vehicles, underwater exploration, aerospace missions, after the reaction of the discharge of water, non-polluting and high efficiency. Due to the current limitations of fuel cell reliability, cost and durability under complex working conditions, pure fuel cell vehicles can not yet be widely put into the market, and the actual operation shows that the development direction of fuel cell vehicles may be hydrogen-electric hybrid power system. Fuel cells are usually connected in parallel with storage batteries and super capacitors (SC) to supply energy to the vehicle.

Ford's Focus sedan plug-in fuel cell hybrid uses a fuel cell - lithium-ion battery structure, combining the advantages of the two types of batteries, improved reliability and longer life. Honda's FCX uses a fuel cell combined with a supercapacitor, and the structure is characterized by high efficiency and a long lifespan [18]. Tu Xiong carried out component selection and design for a fuel cell- battery hybrid drive light bus powertrain, and designed a proton exchange membrane fuel cell (PEMFC-lithium-ion battery with improved fuel economy over the prototype [19]. PEMFCs have been demonstrated in the manufacture of Autonomous Underwater Vehicles (AUVs) for UAV [20]. This type of fuel cell is also the best propulsion method for small commercial UAVs, and the current fuel cell UAVs are Doosan DS30W, Jupiter-H2 by FlightWave in collaboration with Intelligent Energy, and Corbett Griflion H.

4. Issues and Challenges Facing Hybridization

Although hybrid technology is quite mature in Europe, America and Japan, the country still needs to optimize its development strategy in terms of technology development, and the current control strategy still needs to be improved. The energy density of renewable energy still needs to be improved, and the application cost of hybrid technology is high. For fuel cell structure, hydrogen delivery, hydrogen storage, and battery management still need to be improved. Plug-in hybrids need to improve fast charging technology and battery materials. Electrical components are susceptible to ambient temperatures leading to system failures, and when the system has multiple power sources, resource allocation will be more complex, requiring optimized management strategies. Currently put on the market hybrid power system has two or more power sources, in the case of ICE drive, series hybrid system needs the size and power of the drive motor or additional generator, the whole vehicle mass becomes larger, after the energy conversion efficiency is reduced. In addition, hybrid systems also face challenges such as powertrain component design and system modeling simulation.

5. Optimization Strategy

5.1. Design optimization: use of new materials

In order to realize the development of more efficient hybrid systems, a breakthrough in the research of new materials is needed. For automobiles and engineering equipment, lightweight materials can reduce drag; plastics and composites are gradually being used in automobiles. The use of rare earth materials in power batteries can reduce pollution, and most new energy vehicles use rare earth permanent magnet synchronous motors [21]. Rare earth materials are used in power batteries to reduce pollution. Hybrid power systems in the power battery materials have made great progress, lithium -titanium oxide (LTO) batteries are lightweight, lower inherent voltage, has a higher safety than conventional lithium -ion batteries, and can be quickly recharged, can be applied to the marine market, especially in high-speed boats have obvious advantages [22]. The development of sodium-ion batteries is promising. The use of different forms of energy and new alternative energy sources in hybridization is conducive to the alleviation of environmental problems such as the current fossil energy crisis.

5.2. Strategy optimization: control strategy optimizations

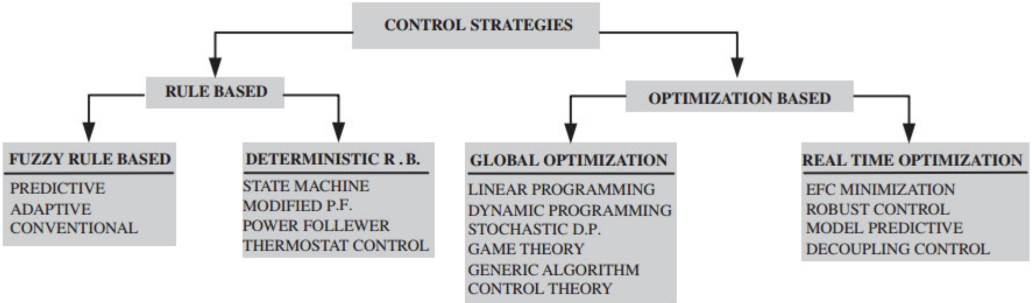


Figure 3. Energy management control strategies [23]

Powertrain control is the core of hybrid technology. Optimization of control strategies is an important research direction in the future. The current control strategies include fuzzy rule based, deterministic rule based and optimization based, as shown in Fig.3. Recent studies have proposed that machine learning-based control algorithms, such as online Deer Reinforcement Learning(DRL) can effectively control the power [24]. The control strategy is formulated to allocate the power of the motor and engine according to the changes in the state of charge (SOC) and speed of the battery, and to switch the operating mode according to the driving demand and working conditions. The control strategy should take into account energy saving, emission, performance, component reliability, battery life and other aspects, so that the mechanical components and systems to achieve the best match, in order to achieve a reasonable allocation of energy, thereby enhancing efficiency. Wei Ling et al. found that the SOC threshold value of the traditional oil trolley is unreasonable, and proposed the minimum fuel consumption control, and the test results can recover nearly 1.3 times of energy compared with the traditional model, and the ability to control fuel consumption is stronger [25]. Zhengyu Yao et al. proposed an offline – online DRL strategy, called HDDPG, which utilizes offline vehicle data for initial modeling and then online learning to improve the training efficiency, and the HEV powertrain can be effectively controlled by the HDDPG under an unknown driving cycle [24]. B.M. Baumann proposes a load balancing vehicle operation strategy and the fuzzy logic controller required to implement it, then a new technique for system integration and component sizing, and finally simulation experiments on the previously proposed control strategy and system design, resulting in an increase in fuel economy from 40 mph to 55.7 mph under the Federal Urban Driving Schedule (FUDS) efficiency increased from 23% to 35.4%.

5.2.1. Series hybrid systems

Using a plug-in series hybrid bus as an object, Wang Suen modified the number of engine switches and operating points in the original control strategy of the software ADVISOR, realizing the improvement of fuel economy and the reduction of costs with comparable dynamics. For the series hybrid electric vehicle engine, Tsinghua University added neuron adaptive control on the basis of traditional PID control, so that the engine speed change is controlled at ≤±5%, with good control effect.

5.2.2. Parallel hybrid systems

Kong Lingtao establishes a quasi-static simulik model of HEV component module, formulates a sub-optimal control strategy, and analyzes the fuel economy under MVEG-95 cycle conditions through simulation, which proves the effectiveness of the control strategy, and the range of deviation of the SOC value is controlled, with a fuel saving of more than 30%. Qin Dazheng et al. combined the threshold value and transient optimization method to design the energy management optimization control strategy for plug-in parallel single-motor hybrid vehicles, and adopted the transient optimization algorithm, genetic algorithm, and simulation experiments using the MATLAB/Simulik platform, and the results showed that the proposed energy management strategy was effective in the Urban Dynamometer Driving Schedule (UDDS), Highway Fuel Economy Test cycle(HWFET), and the New European Driving Schedule (NEDC) [26].

5.2.3. Engine control

According to different cycle conditions and driving mileage, the SOC critical value is calculated and corrected to determine the moment of starting the engine, which can shorter the charging time, extend the battery life and improve the fuel economy. The length of driving distance will affect the engine running time, and as for the long distance, engine start and stop will affect the economy efficiency of the whole vehicle. The School of Automotive at Tongji University optimizes the engine start-stop strategy in different working conditions based on a plug-in series hybrid vehicle for the case where the driving range is greater than the pure electric range. Through calculation and simulation, it is concluded that for the initial battery full charge, under NEDC working conditions, the engine is started when the SOC is reduced to 66%, and shut down when it is 54%, the engine running time is halved, and the energy loss is reduced; for HWET working conditions, the engine should be started after the battery is depleted in order to make full use of the electric energy. For the optimization during the initial undercharge and extended mileage, the method of correcting the SOC value is also used to save energy and reduce emissions [27].

6. Conclusions and Expectations

6.1. Conclusions

An overview of the development and future trends of hybrid technology, an overview of the structure of hybrid technology as well as the forms of energy and their practical use under various classifications, and an analysis of future optimization strategies for the technology, in which a simulation case study of the optimization of the control strategy is presented.

6.2. Expectations

The future development of hybrid technology in terms of control strategy tends to be combined with machine intelligence learning, intelligent control, neural networks (NN), in which NN has been used to manage the energy utilization of FC hybrid propulsion systems; in terms of energy forms, structural modeling, there may be more applications of new materials and clean energy. For applications, this technology may be used more deeply in more fields, such as medical, aerospace, and underwater exploration than is currently possible.

References

[1] Høyer, K. G. (2008). The history of alternative fuels in transportation: The case of electric and hybrid cars. Utilities Policy, 16(2), 63–71.

[2] Wang, Q. et al., 2005. Evaluation of energy-saving effects of hybrid power systems for construction machinery and simulation research on energy saving of hydraulic systems. Chinese Journal of Mechanical Engineering, 12: 135-140.

[3] Zhu, Y. et al. (2022). Design of Series Hybrid Power System for Fixed-wing Vertical Take-off and Landing Unmanned Aerial Vehicle. In: China High Resolution Earth Observation Conference 2022. Beijing. pp. 222-234.

[4] Florentsev, Stanislav et al. (2010). Complete traction electric equipment sets of electro-mechanical drive trains for tractors. 2010 IEEE Region 8 International Conference on Computational Technologies in Electrical and Electronics Engineering (SIBIRCON). IEEE.

[5] Liu, Y. et al. (2016). Project design of extended-range diesel-electric hybrid forklift. Hoisting and Conveying Machinery, 03:11-12+80.

[6] Zhang, S. (2020). Global Release: FPT and Steyr Jointly Develop New Hybrid Tractor Concept. China Machinery and Equipment Trade News. https://news.21-sun.com/detail/2020/01/2020010808483770.shtml

[7] Kang, G. and Sun, Z. (2015). Design and simulation for general aircraft electric-hybrid system. Journal of Shenyang Aerospace University, 32(02):23-27.

[8] Li, L. et al. (2022). New parallel and hydraulic hybrid power system and its strategy of energy management. Journal of Machine Design, 39(02):30-39.

[9] Wang, X. (2012). Parameters Matching of Hybrid Forklift Power Devices and Research of Energy Control Strategy. Thesis of Shandong University of Technology.

[10] Gong, J. et al. (2014). Evaluation of energy saving effect of hybrid forklift and test of energy saving system. Journal of Jilin University (Engineering and Technology Edition), 44(01):29-34.

[11] Kang, J. (2022). Design of Dynamic Coupling System for Series-parallel Hybrid Electric Tractor. Thesis of Henan University of Science and Technology.

[12] Gui, L. and Li, Q. (2021). Research on Electro-hydraulic Composite Control System of Parallel-series Hybrid Electric Vehicle. Machine Building & Automation, 50(06):228-231+238.

[13] Li, Y. et al. (2006). Dynamic Analysis and Simulation with Lagrange Equation on Hydraulic Excavator. Hydromechantronics Engineering, 10:170-171.

[14] Baseley, S., et al. (2007). Hydraulic hybrid systems for commercial vehicles. SAE Technical Paper, 01: 4150.

[15] Fan, X., et al. (2019). Design of Shipborne Constant Pressure Pressurized Tank and Constant Pressure Control. 2019 IEEE 8th International Conference on Fluid Power and Mechatronics (FPM). IEEE.

[16] Matheson, P., and Jacek Stecki. (2003). Development and simulation of a hydraulic-hybrid powertrain for use in commercial heavy vehicles. SAE transactions, 114-123.

[17] Hui, S., and Jing J. (2010). Research on the system configuration and energy control strategy for parallel hydraulic hybrid loader. Automation in Construction, 19(2): 213-220.

[18] Ma, Z., and Zhang, D. (2008). Technical research on power system of hydrogen-electric hybrid fuel cell vehicle. Power Technology, 357-360.

[19] Tu, X. (2013). Research on Design and Optimization of Power System of Fuel Cell/Battery Hybrid Vehicle. Thesis of Chongqing Jiaotong University.

[20] Mendez, A., Teresa J. Leo, and Miguel A. Herreros. (2014). Current state of technology of fuel cell power systems for autonomous underwater vehicles. Energies, 7(7): 4676-4693.

[21] Hou, J. (2016). The Application of New Materials in New Energy Vehicles. Science and Technology & Innovation, 107-108.

[22] Liu, Z., et al. (2019). The Development of Domestic Diesel-Electric Hybrid Marine Propulsion Systems and Typical Application Cases. Disel Engine, 41(4):46-49.

[23] Bayindir, K., Çağatay, M., Gözüküçük, M., & Teke, A. (2011). A comprehensive overview of hybrid electric vehicle: Powertrain configurations, powertrain control techniques and electronic control units. Energy conversion and Management, 52(2), 1305-1313.

[24] Yao, Z., Yoon, H. S., & Hong, Y. K. (2023). Control of hybrid electric vehicle powertrain using offline-online hybrid reinforcement learning. Energies, 16(2), 652.

[25] Wei, L. & Geng, D. (2021). Simulation of Minimum Fuel Comsumpution Control of Hybrid Electric Vehicle under Different Working Conditions.38(08):148-151+395.

[26] Qin, D., et al. (2013). Energy Management Optimization Control Strategy of Plug-in Parallel Single-motor Hybrid Electric Vehicle. China Journal of Highway and Transport, 26(05), 170-176.

[27] Li, X., et al. (2011). Optimization of Control Strategy for Engine Start-stop in a Plug-in Series Hybrid Vehicle. Automotive Engineering, 33(02), 112-117+132.