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Research Status of Extended-Range Electric Tractors

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Abstract: The traditional oil tractor has problems with high energy consumption and considerable gas pollution during operation. To ensure power and endurance, it has better economy to install the range extension scheme on the tractor. Based on the existing research results, the working mode, power system design, and energy management strategy of extended-range tractors are reviewed, and the characteristics of existing extended-range tractors are analyzed. On this basis, this type of tractor's shortcomings and future research directions are pointed out.

1. INTRODUCTION

With agricultural machinery becoming more intelligent and multi-functional, the efficiency and technical level of mechanization and automation in agricultural production have been successfully improved. Still, this process also brings higher fuel consumption and environmental pollution problems [1, 2]. New forms of modern agriculture have put forward higher and higher requirements for ecology, energy saving, and environmental protection, and sustainable and environmentally friendly solutions are increasingly important to support the development of modern agriculture [3].

Tractors, as power machinery, play an essential role in agricultural production, but traditional fuel tractors are high in consumption and, at the same time, produce a lot of pollutants and do not meet the requirements of today's green, sustainable development. With the enhancement of global awareness of environmental protection and the rapid development of intelligent and electricized technology, especially the remarkable breakthroughs in batteries, motors, and electronic control systems in the field of electric vehicle technology, a solid foundation has been laid for the progress of electric tractor technology [4]. Although electric tractor technology shows great potential with its zero-emission and pollution-free environmental characteristics, it still faces the problem of endurance limitations caused by a single energy system [5]. The addition of range extenders to electric vehicles can effectively improve the endurance of tractors, optimize the design of power systems, and improve energy management strategies, which can effectively improve fuel economy, and relevant researchers and enterprises have begun to study and produce this type of tractors.

This paper summarizes the working mode, power system design, and energy management strategy of the extended-range tractor, as well as the characteristics of the relevant models. On this basis, the applicable technical research suggestions are put forward to provide a reference for developing and promoting the extended-range electric tractor.

2. EXTENDED-RANGE ELECTRIC TRACTOR SYSTEM MECHANISM AND OPERATION MODE

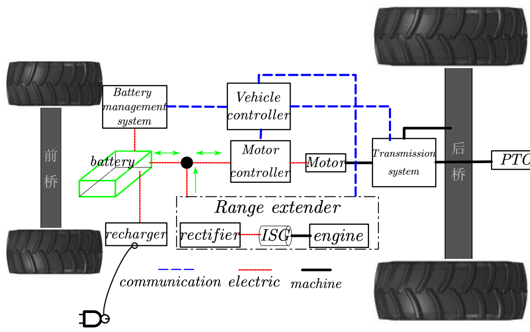

Figure 1. Extended-range electric tractor structure diagram

The structure of the extended-range electric tractor is shown in Figure 1, and the power structure is mainly composed of a range extender, a motor, a battery, a transmission system, and related electrical and communication components. The range extender is composed of a diesel engine, generator, rectifier, etc., as the power supply equipment of the vehicle power system, it can indirectly or continuously provide electric energy to the generator. Because the range extender is not rigidly connected with the transmission parts, the fluctuations generated by the tractor during operation will not affect the working state of the diesel engine, and the diesel engine can work smoothly in the efficient range, improving fuel economy.

Extended-range electric tractors and extended-range vehicles have similar operating modes. Still, because of their unique operating environments and needs, there are significant differences in specific control and conversion strategies. The extender tractor can be divided into four operating modes in daily operation according to the power reserve and working conditions. ① Pure electric mode: When the battery power is sufficient, there is no difference between the extended-range electric tractor and the electric tractor, and the tractor operation energy comes from the battery. Zero emissions can be achieved. ② Extended range mode: When the power consumption reaches a specific range, the range extender starts, and the tractor has two energy supply units. ③Driving charging mode: When the battery power consumption is in a particular range, and the tractor power consumption demand is not significant, the range extender is in the working state, the electricity generated in addition to the supply-demand, and the battery power supply supplement. ④ Parking charging mode: extended-range electric tractors are often equipped with external charging interfaces, which can be charged or the battery replaced at a nearby charging platform after completing the tractor operation to complete the energy supplement. Another scenario is that at a distance from the charging platform, the tractor can park at the same time the range extender starts working to complete the power supply to the battery.

3. RESEARCH STATUS OF EXTENDED-RANGE ELECTRIC TRACTORS

3.1 Power system matching design

The design of the power system determines the reliability and compliance of the torque transmission of power machinery. Some researchers have researched the design and optimization of the power system of electric tractors with extended ranges. Based on the traditional diesel tractor, Zhao Jinghui [6] designed the motor power and speed required by the extension-range tractor and verified the reliability through simulation analysis. Aiming at the problems of low traction efficiency and significant system energy loss of distributed drive electric tractors, Li Xianzhe [7] proposed a parameter optimization design and verification method for a distributed drive system based on a multi-island genetic algorithm. The optimized results showed that the tractor's maximum tractive force and average efficiency had been greatly improved. Liu[8] proposed a parameter-matching optimization method based on the weight coefficient of the performance index of the electric tractor with demand extended range and verified the model's effectiveness through simulation. Lan et al. [9] proposed a new matching method for extended-range electric vehicles, which optimized power transmission efficiency based on the two standards of waste heat recovery power generation and high net power density. Compared with the original generator, the net power density was increased by 11.6%, and the fuel economy was reduced by 1.7% compared with the equivalent fuel consumption of traditional extended-range electric vehicles. Wu Kehong [10] took the traditional 40-horsepower fuel tractor as a reference, analyzed the driving force and traction resistance of the tractor during operation, determined the parameters of the main components of the tractor motor, gearbox, and generator, built a simulation model based on Simulink software, and simulated and analyzed the performance of the tractor before and after the transmission ratio optimization. Xu Liyou [11] proposed a torque distribution strategy based on fuzzy logic to solve the torque distribution problem of front and rear wheel drive of an extended range four-wheel-drive electric tractor. The test proved that the strategy reduced the tractor's maximum front wheel slip rate by 16.5%, while the maximum rear wheel slip rate increased by only 2.2%, effectively controlling the tractor slip rate within a reasonable range.

3.2 Research on Energy Management Strategies

Energy management strategy determines the energy consumption and performance of the vehicle [12]. In the field of new energy vehicles, energy management strategies have been developed for a long time and are relatively mature, and some methods can be used for reference. However, the working conditions of extended-range electric tractors are complex, and the control strategies related to automobiles cannot be fully adapted to the working conditions, so it is necessary to research energy management strategies suitable for extended-range electric tractors. According to the principle of mathematical modeling, existing energy management strategies can be divided into two categories [13], and the specific classification is shown in Figure 2. Generally, the extender range electric tractor adopts the thermostat, power following, and mixed thermostat strategies [14-16]. Luo Guangju [17] proposed SOC power following and fuzzy reasoning energy management strategies, analyzed and formulated the strategies, built a simulation model in MATLAB/Simulink software, and embedded the developed three energy management strategies into the simulation model, laying a foundation for the joint simulation of energy management strategies. Fang Shuping [18] formulated thermostats and power-following strategies and proposed fuzzy control energy management strategies based on these strategies. Under plowing conditions, three strategies were used for simulation analysis regarding battery charging state and economy, respectively. Li Yanying [19] designed thermostats energy management strategy and thermostats + braking energy recovery energy management strategy and completed the co-simulation of vehicle simulation software AVL-CRUISE and energy management strategy simulation software MATLAB/SIMULINK through AVL-Interface co-simulation. Lee[19] optimized the energy management strategy of the parallel hybrid tractor system, resulting in the tractor's energy consumption being 11.78% less than that of conventional tractors.

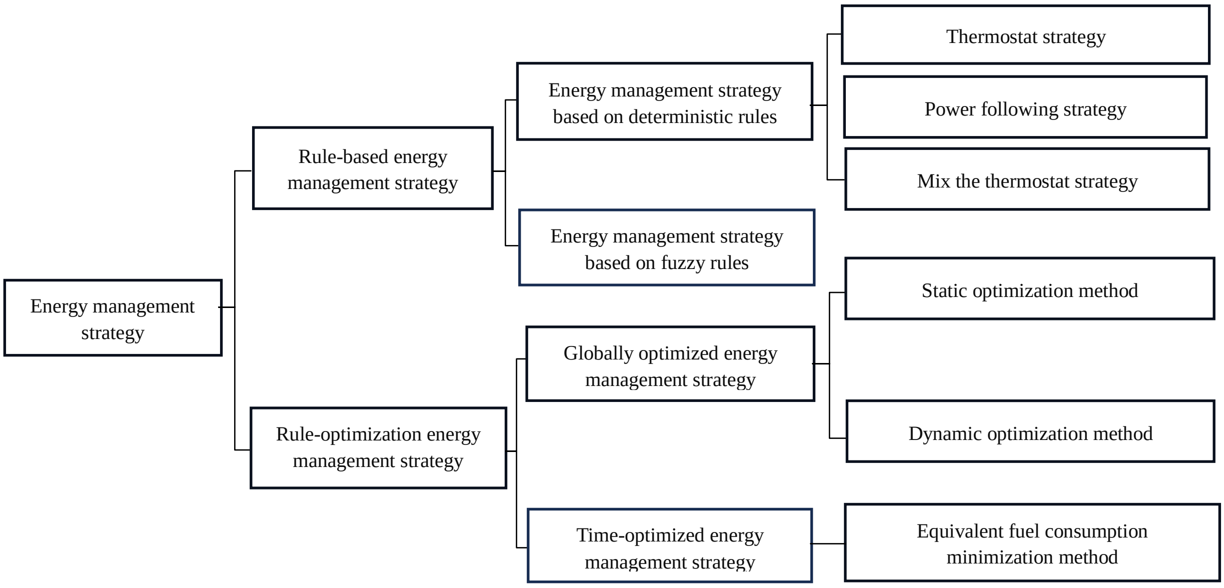

Figure 2. Classification of energy management strategies

4. RESEARCH TREND OF EXTENDED-RANGE ELECTRIC TRACTORS

Tractors need long endurance and reliability when operating in the field, which requires extended-range electric tractors to ensure low energy consumption in the development process; the focus should be on considering the endurance and reliability issues. On this basis, there are many technical problems to overcome, including but not limited to the power transmission system parameter matching design, control strategy formulation, battery and energy management technology, and system experiment simulation technology.

(1) Power system design. Reliability, efficiency, and conciseness should be the future extender electric tractor power system design criteria, which can give play to the advantages of electric tractors. At the same time, the optimization of power parameters should adopt multiple optimization objectives and fuel consumption should not be considered. For example, tractor escape ability, power transmission efficiency, and vehicle handling performance should be considered.

(2) Energy management strategy research. It is necessary to increase the research on identifying and predicting cycle conditions. Various existing control strategies will be affected under different cycle conditions, but the uncertainty of working conditions exists in practical applications. Introduce condition identification technology and adopt different management strategies according to condition and demand.

(3) Integration of structure and system optimization. It is necessary to develop chassis technology suitable for extended-range electric tractors. In the past, a large part of the research was carried out on the traditional fuel tractor, which caused the unreasonable layout of the tractor chassis after the transformation and affected the tractor's performance.

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