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Off-grid Automobile Wireless Charging System Based on Photovoltaic Energy Storage

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Abstract: With the development and popularization of new energy vehicles, more and more electric vehicles have entered the public's vision, and gradually replaced the traditional fuel vehicles to become a good partner for people to travel. However, electric vehicles have problems such as slow charging process, short driving range, insufficient number of charging piles, and the energy structure of municipal power dominated by thermal power also restricts the emission reduction ability of electric vehicles. The establishment of off-grid optical storage wireless charging system will greatly alleviate this situation. The system uses photovoltaic as a source of all energy, which can be distributed in the open space on both sides of the highway and municipal roads, and the charging base is arranged in the safety zone on both sides of the road or at the traffic light intersection. Its energy storage facilities can ensure the stability of the photovoltaic system power supply and meet the needs of car charging. By optimizing the energy storage battery capacity, photovoltaic panel layout and number, inverter and wireless charging system circuit structure will greatly improve the efficiency and reliability of the charging system, making it possible to use on a large scale.

Keywords: Photovoltaic, Energy storage, Wireless car charging.

1. Introduction

In recent years, with the proposal of China's "carbon peak, carbon neutrality" goal, and increasingly severe environmental problems, the electric vehicle industry has been rapid development, more and more vehicles have been put into large-scale use in all walks of life. For example, ride-hailing, law enforcement vehicles and even special vehicles such as mining trucks have achieved large-scale electrification changes. But today, the charging problem of vehicles is still troubling the majority of users. The charging efficiency of electric vehicles has been effectively improved in the process of increasing the power of charging piles, but the shortage of charging piles has not been solved. Moreover, it is worth noting that due to the instability of new energy, thermal power is still the main source of electricity in China's power grid, accounting for about 66% of the total electricity [1]. Therefore, the energy consumption of electric vehicles is not zero carbon, and this problem needs to be solved. A set of efficient and entirely renewable energy charging technology will solve this series of problems: photovoltaic and energy storage based electric vehicle wireless charging system. First of all, this system introduces photovoltaic as its total energy source completely carbon-free, second, the energy storage facility will ensure the stability of the EV charging process. Wireless charging facilities can be arranged in temporary parking areas on both sides of the road, which will greatly reduce the problem of finding land during the charging process of the vehicle. In addition, the temporary roadside parking area that is often vacant will also ensure that the vehicle can have enough electricity to charge at the fast charging point in case of emergency, alleviating the range anxiety of electric vehicles over long distances. The charging method without charging port can also effectively avoid the corrosion of the charging interface such as dust and rain. Charging without the driver having to get out of the car can also keep the owner safe on the highway.

2. Photovoltaic Part Design Principle

Photovoltaic energy storage system mainly includes photovoltaic power generation array, energy storage battery array and charging control system. Taking highways as an example, photovoltaic arrays can be placed on both sides of the highway or in the middle of the fence, and connected to the charging base on both sides of the road through electrical wiring and control systems. The conversion process of photovoltaic power generation per unit area is shown below[2]:

$$E_T = E_b \times R_b + E_d \times \frac{1+\cos\beta}{2} + E \times \rho \times \frac{1-\cos\beta}{2} \tag{1}$$

E_b refers to direct solar radiation on a horizontal plane; R_b refers to the ratio of direct radiation flux on the inclined plane to the horizontal plane, refers to the tilt Angle of the photovoltaic array, E_d refers to the solar scattered radiation on the horizontal plane, refers to the reflectivity of the ground, E refers to the total solar radiation on the horizontal plane.

According to the relevant literature test data, the energy conversion efficiency of monocrystalline silicon photovoltaic panel is about 20%, the energy conversion efficiency of inverter is 98.4%, and the energy efficiency of photovoltaic power generation system is about 81.14-87.87% (W_{in}/W_{out}) [3].

The photovoltaic power generation per unit area per unit time can be obtained by calculating the following formula.

$$W_{out} = E_T \times Q_t \times Q_n \tag{2}$$

Where E_T is the direct radiation power, Q_t is the photoelectric conversion efficiency of monocrystalline silicon photovoltaic panel, and Q_n is the efficiency of photovoltaic power generation system.

According to the solar irradiance data of the deployment area, MATLAB is used to calculate the hourly irradiance and calculate the full-day power generation of the photovoltaic system. It can provide relevant data for the subsequent energy storage configuration.

3. Energy Storage Part Design Principle

In the photovoltaic wireless charging model, the energy storage system is responsible for the stable output of electric energy and the continuous supply of electric energy at night. Therefore, its main design includes battery series parallel design and battery capacity quota. In order to fit today's mainstream electrochemical energy storage methods, the following will take lithium iron phosphate batteries as an example.

The selected battery is a commercial square lithium iron phosphate battery composed of positive collector fluid (aluminum foil), negative collector fluid (copper foil), positive material (nickel cobalt aluminum), negative material (graphite), diaphragm, electrolyte, safety valve, positive cap, washer, shell, etc. The battery capacity is 280 Ah. When the battery is working, it is charged to 3.65V, and then discharged to 2.50V at constant power [4].

Taking electric vehicle charging voltage 800V[5] and charging power 250kW as an example, the inverter system is simulated by MATLAB as shown in the following figure.

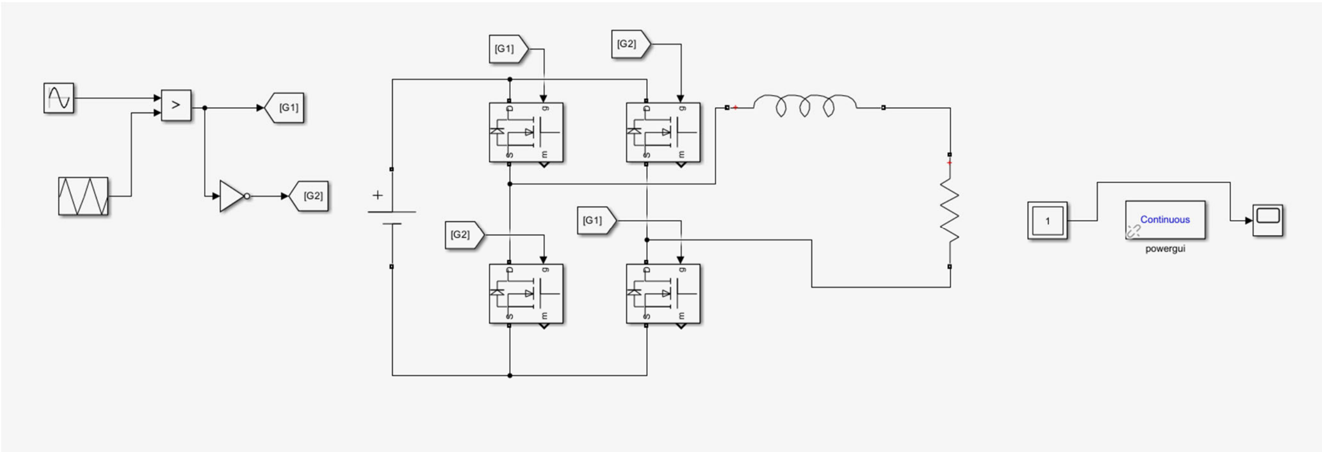

Figure 1. Inverter model

The output voltage of the battery is 800V, the charging power is 250kW, and the minimum output voltage of a single battery is 2.5V and the minimum output current is constant 1A. The calculation results show that a single container cabinet should be 320S312P. In the specific implementation process, a battery container can be divided into several arrangements according to the battery types provided by the battery cabinet manufacturers. This will facilitate battery heat dissipation and fire safety design.

The determination of the capacity of energy storage facilities should consider the capacity of photovoltaic power generation and the demand for highway vehicle charging. In large power stations, the quota ratio of energy storage and new energy is about 1/10, but the energy storage quota can be appropriately increased under the tram charging condition. This is mainly because of the inevitable loss of power generated by the coil during the wireless charging process.

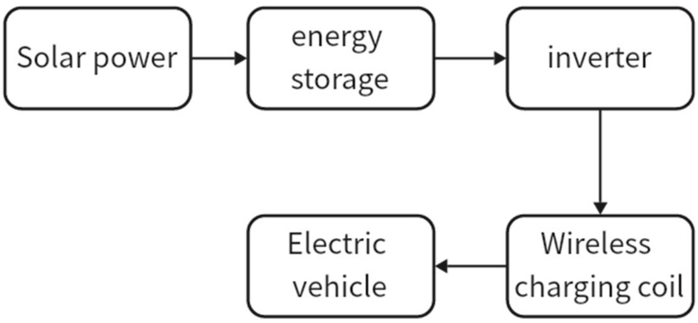

Figure 2. Photovoltaic wireless charging system diagram

4. Wireless Charging Part Design Principle

The wireless charging system selects the wireless charging mode of coil mutual inductance. The wireless charging system includes three parts: inverter, coil and compensation network. Its basic network is shown in the figure below. It includes a primary DC power supply and a secondary battery charging system. To simplify this part of the model, the cell on the secondary side is simplified into a resistance element and its input current and power are measured. Among them, the mutual inductance coil used is a generalized mutual inductance model.

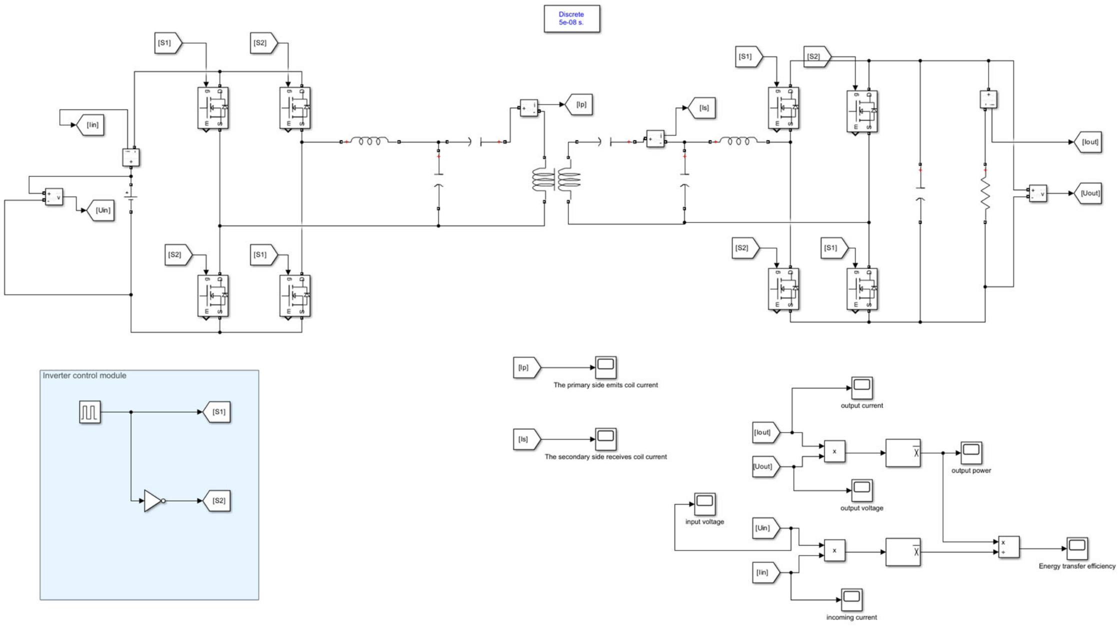

Figure 3. Wireless charging system diagram

The sub-side output current, voltage, power, and energy transmission efficiency are shown in the figure below.

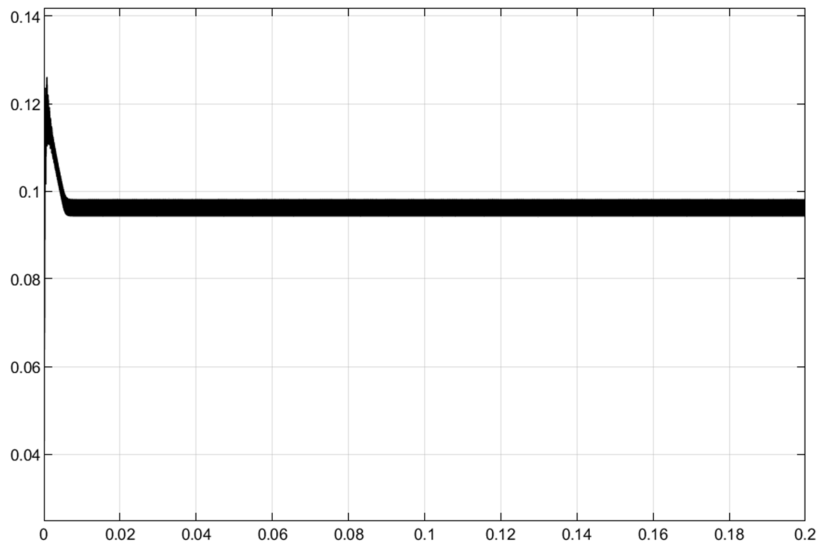

Figure 4. Battery charging current simulation diagram Unit 10A

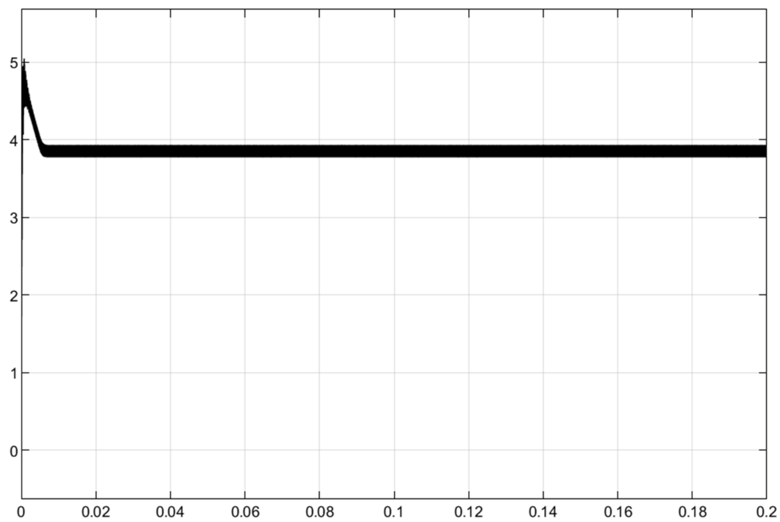

Figure 5. Battery charging voltage simulation diagram Unit 100V

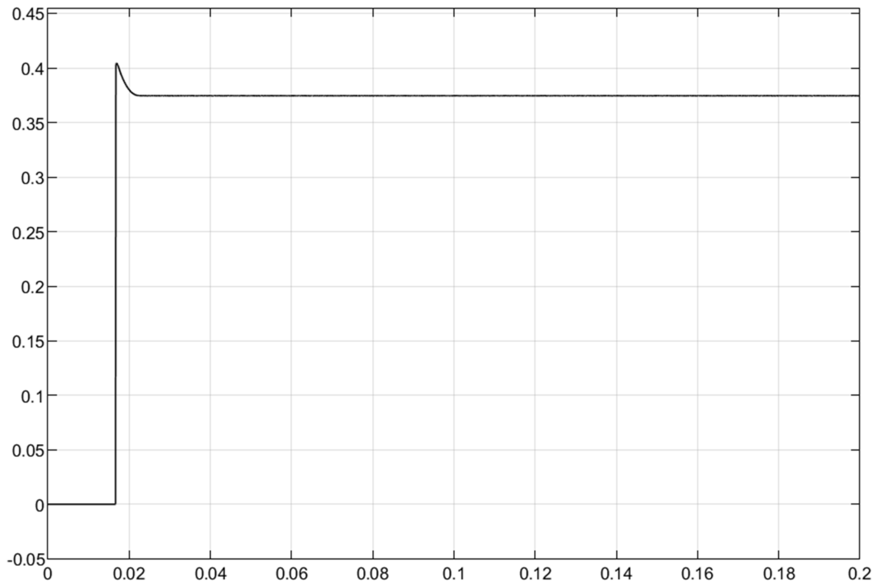

Figure 6. Battery charging power simulation diagram Unit 1000W

According to the final receiving resistance charging power, the charging power of the wireless charging system to the tram is about 370W when the output energy storage battery is 800V. In order to improve the charging power, we can reduce the iron loss and copper loss in the coil by using reactive power compensation, optimizing the coil parameters, changing the capacitance and inductance parameters in the circuit.

5. Wireless Charging System Optimization Process

5.1. Photovoltaic optimization

Photovoltaic optimization process includes photovoltaic panel area optimization and inverter performance optimization. The PV panel area optimization process should first investigate the charging needs of the vehicles in the road section and predict the daily electricity consumption. The process can be optimized using genetic algorithms in MATLAB to find the minimum PV panel area and minimum cost. Specific operations are as follows:

Firstly, the daily number of charging vehicles and power consumption of a charging station in the road section in a year are investigated, and the daily average value is calculated. According to the energy conversion efficiency of the charging system, the daily required photovoltaic power generation is calculated, and the number of photovoltaic panels required is calculated based on this.

For the selection of photovoltaic panel installation points, regional discretization analysis can be used [6]. Because there may be trees or houses blocking the sun along the highway or highway, the area does not have the conditions for the construction of photovoltaic modules. In order to facilitate the analysis, this paper uses a grid of specific size to discretize the road area. The roadside area is divided by a specific small square, and the circle is marked as having sufficient light area.

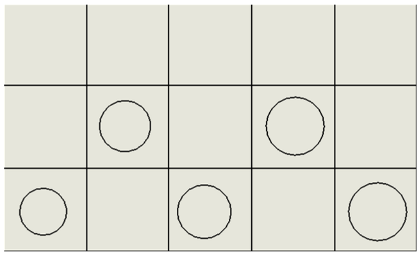

Figure 7. Results of highway side discretization

Taking the maximum installation area of PV modules as the target to calculate the PV capacity that can be installed beside the highway, the optimal layout model of PV modules is a maximum coverage model, that is, in the limited areas on both sides of the road, the PV modules cover as much as possible the areas that can receive solar radiation. The constraints of the objective function include boundary constraints on both sides of the road, foreign body constraints on the side of the road, photovoltaic panel coverage constraints in the radiation area, and photovoltaic panel orientation constraints.

In addition, the energy conversion efficiency of photovoltaic panels can also be optimized, such as selecting a monocrystal silicon photovoltaic panel with high energy conversion efficiency, installing a single axis rotation device for the photovoltaic system and equipped with a ray tracing instrument.

Inverter optimization includes the following processes.The inverter can assume the function of reactive power regulation. While supplying power, distributed PV has the ability to flexibly adjust reactive power, and the voltage can be adjusted to the photovoltaic junction point by controlling the emission or absorption of reactive power [7].

The relationship between the adjustable reactive capacity of the inverter and its rated capacity and active output power is as follows:

$$Q_{\boldsymbol{max},PV} = \pm\sqrt{S_{INV}^2 - P_{PV}^2} \tag{3}$$

$Q_{max,PV}$ is the reactive power adjustable capacity of photovoltaic inverter; S_{INV} is the rated capacity of photovoltaic grid-connected inverters, generally 1.0 to 1.1 times the rated power of photovoltaic panels; P_{PV} is the active power of photovoltaic connected to the grid.

5.2. Wireless charging is optimized

The optimization process of wireless charging technology can not only modify the original parameters such as capacitance and inductance in the circuit, but also carry out static anti-drift design. Sonapreetha et al. [8] studied the setting of non-overlapping coils as a wireless fixed electric vehicle charger detection for foreign bodies and vehicle positions. Deng et al. [9-10] detected the edge and position of electric vehicles by capturing the phase Angle difference of induced voltage and current. Hasan et al. [11] analytically described the time-varying power transmission and efficiency distribution, and proposed a power transmission control algorithm independent of coil position detection. Lu et al. [12] studied a hybrid radio energy transmission system based on capacitance-inductance (CL) compensation. Feng et al. [13] proposed a method for road traffic monitoring through magnetic sensors, using multiple magnetic dipoles to simulate vehicles in motion, and modeling local magnetic field disturbance caused by moving vehicles for vehicle identification and speed estimation. Xu Shihui et al. [14] studied a new type of square coil and proposed an optimized close-range accurate positioning method, which solved the problem of large error in traditional positioning methods of magnetic dipole model. Chen et al. [15] conducted a review study on the development of dynamic radio energy transmission technology. Baiye Hong et al. [16-17] used traffic simulation and nonlinear optimization methods to study the length of charging lanes to minimize system costs.

5.3. Energy storage partial optimization

In conventional new energy power plants, the capacity of energy storage equipment generally needs to reach 10%-20% of the total installed capacity of the power plant to ensure the safe and stable operation of the power plant, and play the role of "peak cutting and valley filling".

In the field of automobile wireless charging, energy storage must first consider the load characteristics of the charging system, determine the threshold of the charging and discharging state of the energy storage, and build a better operating condition and operating conditions of the road vehicle charging system with optical storage. Secondly, with the goal of maximizing photovoltaic utilization and minimizing system investment and operating costs, particle swarm optimization algorithm is used to optimize the solution, and the optimal photovoltaic and energy storage capacity of the optical storage bus charging station is determined. He Xin et al. [16] concluded that a more reasonable PV and energy storage capacity could be obtained by considering load characteristics and operating conditions under the same configuration. In their research, the moving boundary method is mainly used to determine the charging and discharging threshold of energy storage, which can meet the requirements of accuracy and stability.

The main design in this paper is an off-grid wireless charging system, so all energy sources and consumption are completed in a small range [17-19]. The specific working conditions are divided into the following two parts: (1) photovoltaic as the energy source of the charging system, electric vehicles and energy storage as the photovoltaic consumption object. (2) photovoltaic and energy storage as the energy source of the charging system, and electric vehicles as the consumption object of photovoltaic and energy storage. The following objective functions and constraints are used in the optimization process.

The first objective function is the lowest comprehensive daily operating cost of the optical storage and charging system.

$$C_1 = \frac{(C_{pv}\times\frac{r(1+r)^{m_1}}{(1+r)^{m_1-1}}+C_{battery}\frac{r(1+r)^{m_2}}{(1+r)^{m_2-1}}+C_{conversion}\frac{r(1+r)^{m_3}}{(1+r)^{m_3-1}})}{365} \quad (4)$$

$$\min F_1 = C_1 + C_2 \quad (5)$$

C_1 is the equivalent daily cost of the initial construction of the charging system; C_2 is the daily maintenance cost of the charging system. The following are the remaining objective functions.

$$C_{pv} = C_v P_{max}^{pv} \quad (6)$$

$$C_{battery} = C_e E + C_p P_{b.max} \quad (7)$$

$$C_2 = \frac{k_{bat}C_{battery}}{365} \quad (8)$$

C_{pv} is the photovoltaic cost, $C_{battery}$ is the cost of the energy storage system, $C_{conversion}$ is the cost of the wireless charging system, r is the discount rate, m_1 is the service life of the charging station, m_2 is the life of the energy storage battery. C_v, C_e and C_p are respectively the price of 182 unit capacity photovoltaic components (yuan /kW), the price of unit capacity energy storage battery (yuan /kWh) and the unit price of power conversion device (yuan /kW),Ppvmax, E and Pb.max are respectively the maximum output of photovoltaic system (kW), the capacity of energy storage system (kWh) and the maximum charge and discharge work of energy storage system Rate; k_{bat} is the annual operation and maintenance coefficient of the energy storage system.

The constraints of the off-grid system under two working conditions are as follows:

working condition (1)

$$P_t^{load} = P_t^{pv} + P_t^{battery} \quad (9)$$

working condition (2)

$$P_t^{load} = P_t^{pv} - P_t^{battery} \quad (10)$$

6. Conclusion

The off-grid optical storage electric vehicle wireless charging system is still in the development stage, and the problems facing it are mainly insufficient output power, more energy dissipation during the charging process, insufficient stability of the photovoltaic system, and insufficient life of the photovoltaic panel and battery. However, with the progress of technology and the realization of related optimization, the advantages of wireless charging systems that can be charged anywhere and the charging concept of off-grid photovoltaic energy storage will bring people a green, safe and comfortable travel experience, and will also help the development of new energy technology in the field of transportation.

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