Laser Power Transfer and Conversation Efficiency Optimization Scheme

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Abstract. In recent years, wireless charging technology has developed rapidly, providing many conveniences for people's lives. However, the demand for long-distance wireless charging, such as drones and satellites, is still unsatisfied. This article will introduce the laser power transfer technology, which can meet the needs of long-distance charging, introduce its principle, and compare it with traditional wireless charging methods. At the same time, three current photoelectric conversion efficiency optimization schemes of this technology will be introduced: modified PV receiver geometries, MPPT techniques, and secondary concentrator. Due to the use of special instruments, modified PV receiver geometries and the secondary concentrating method are expensive and difficult to have universality. Still, they are currently in the early stage of development and have great potential. The MPPT techniques have long been used in many photovoltaic fields and have perfect technology, but they cannot work normally under special circumstances, so they still need to be improved.

Keywords: Photoelectric efficiency, conversion efficiency optimization, laser power transfer, wireless charge.

1. Introduction

In recent years, drones have developed rapidly, and today, they are widely used in various fields such as aerial photography, agriculture, transportation, etc [1]. However, the drone battery capacity is limited, making it difficult to work for a long time. Therefore, improving the charging efficiency of drones and even making drones charge at work is a very meaningful research direction.

One such method is Laser Power Transfer (LPT) technology. In LPT technology, lasers are emitted through an optical system onto the photovoltaic panels of electrical appliances (e.g. drones) to provide electrical energy to the consumers. Compared with wired charging, this charging method allows drones and satellites. To continue charging at high altitudes.

At present, the common wireless charging technologies include Inductively Power Transmission (IPT) technology and Magnetic Resonance Power Transmission (MRPT) technology, but the transmission distance of these two technologies is short and cannot meet the needs of charging UAVs in the air. Although LPT technology is still affected by the transmission distance, it has a long transmission distance due to the directionality, monochromaticity, and high brightness of the laser itself.

LPT technology was first proposed by NASA in the 70s of the last centuries, but due to technical limitations, the technology has been slow to develop. At present, this technology has been successfully used in many fields such as mobile phone charging and drone charging [2].

This article will briefly introduce the principles of LPT technology and compare it with traditional wireless charging technology. After that, several methods for optimizing the transmission efficiency of LPT technology will be introduced, and their advantages and disadvantages will be analyzed.

2. The Basic Principles Of LPT Technology

2.1. Photoelectric Conversion Principle

Each atom or electron has a certain energy level, and when these particles exchange energy with the outside world, they will jump between the energy levels and emit photons. However, the particle itself is prone to spontaneous transition from a higher energy level to a lower energy level, and eventually remains in the ground state and cannot continue the transition. In other words, it is difficult for particles to form a stable light source without external interference. However, by applying a continuous voltage to the particle, the transition from the ground state to the high-energy state can be maintained, resulting in the continuous generation of photons and the formation of a laser light.

In the case of PV panels, the principle of power generation comes from the photoelectric effect of the diodes. When P-type semiconductors and N-type semiconductors are combined, a certain potential difference is generated, i.e., the P-N junction. When the P-N junction is irradiated by light, the photons transfer energy to the electrons, causing them to move, thus forming an electric current.

2.2. Principle Of Laser Power Transfer

The core of LPT technology is the above-mentioned photoelectric conversion principle. During the working process of LPT, electrical energy is first converted into light energy in the laser and then back in the photovoltaic panel. The specific workflow is shown in Fig 1: first, the power supply supplies power to the laser, irradiates it to the photovoltaic array through the optical system, converts the light energy into electrical energy, and then rectifies it through the photovoltaic converter to provide power for the drone. At the same time, a control system can be added between the receiver and transmitter to enable the laser to be properly illuminated on the photovoltaic panels [3].

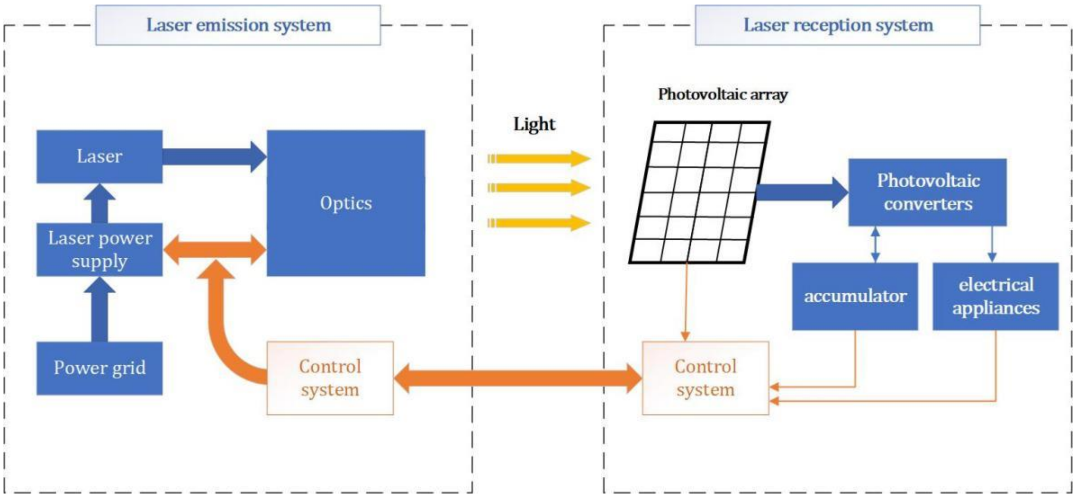

Figure 1. principle of laser power transfer

Semiconductors that convert light energy into electrical energy are also called photovoltaic cells, and different materials and structures affect the photoelectric conversion efficiency of photovoltaic cells. For photovoltaic cells, in the absence of external light, a dark current will be generated from the positive electrode to the negative electrode, and under the condition of light, a reverse photocurrent will be generated. At the same time, with the increase of light intensity, the open-circuit voltage of the battery tends to be constant, while the short-circuit current gradually increases. Therefore, photovoltaic cells should be considered as a source of electric current. The basic equivalent circuit model is shown in Fig. 2:

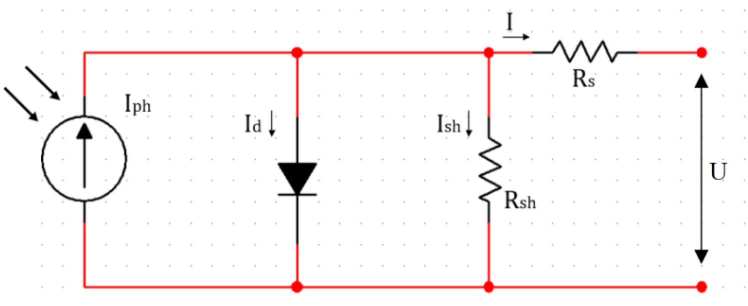

Figure 2. photovoltaic cell equivalent circuit

The equation for the output characteristics is:

$$I = I_{ph} - I_0 \left[\exp(\frac{qU}{nKT}) - 1\right] \quad (1)$$

From the formula, it can be seen that under the premise of keeping the voltage constant, temperature and irradiance (i.e., optical power, the magnitude of the main influence) will affect the output efficiency of photovoltaic cells. At the same time, when the temperature and irradiance remain constant, the voltage increases and the current decays exponentially.

That is, photovoltaic cells have a maximum power.

In addition to the above two factors, the material of the photovoltaic cell itself also has an impact on the energy transmission efficiency. Each material will have a corresponding laser wavelength band, and within this wavelength range, a peak of transmission efficiency can be found.

2.3. Comparison Of Common Wireless Charging Technologies And LPT Technologies

There are many ways to propagate wireless energy, but the most common ones are magnetic coupling and electrical coupling.

MRPT technology first converts electrical energy into magnetic energy, uses a coil to transfer the magnetic energy to the receiving circuit, and then converts the electromagnetic energy into electrical energy. Fig. 3 shows the schematic diagram.

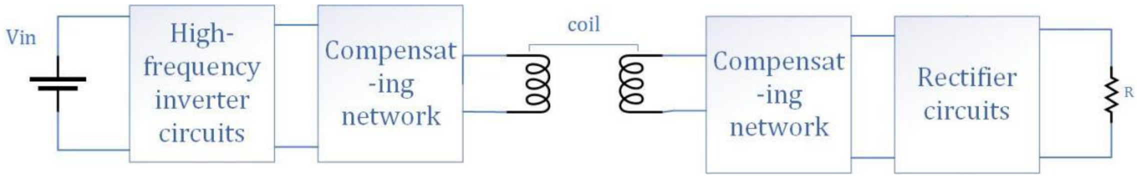

Figure 3. Schematic diagram of MRPT technology

MRPT technology is divided into two categories: electromagnetic induction and resonant coupling. The electromagnetic induction type mainly uses the law of electromagnetic induction, which has a short power transmission distance and high position requirements, but the efficiency of the system is large. In the case of resonant coupling, multiple coils of the same resonant frequency are used to transmit energy under the condition of resonant excitation. It is characterized by its long transmission distance, low sensitivity to misalignment, and the ability to supply power to multiple consumers at the same time.

IPT technology uses capacitors to transfer current by taking advantage of the potential difference generated between the transmitting and receiving plates, as shown in Fig. 4.

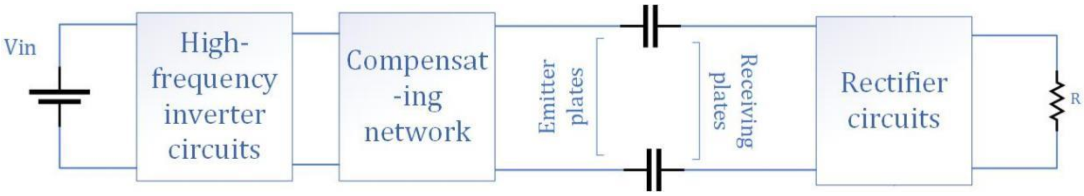

Figure 4. Schematic diagram of IPT technology

Compared to MRPT technology, this method is characterized by its small size, no eddy current effect and less electromagnetic interference. Compared with them, LPT technology has the advantages of longer transmission distance and small receiver aperture, but it is limited by the photoelectric conversion efficiency of photovoltaic converters, and its transmission efficiency is low.

3. Conversation Efficiency Optimization Scheme Of LPT

3.1. Modified PV Receiver Geometries

In order to improve the energy conversion efficiency of the LPT system, different photovoltaic array geometries can be adopted. Typical PV array modifications are round and zigzag. These photovoltaic arrays are characterized by their special geometry and are adapted to the distribution of light, so that the irradiance on each photovoltaic unit remains the same.

The other is the photovoltaic cavity converter (PVCC), which concentrates light into the cavity, and the light is scattered in the cavity, which can not only evenly distribute the irradiance, but also collect the beam to improve the utilization rate of light energy. However, this method has not been able to significantly improve the transmission efficiency of light [4].

The advantage of this method is that it is simple and efficient, and avoids the large amount of computation required for photovoltaic arrays in traditional LPT systems. At the same time, theoretically, PVCC can greatly improve the photoelectric conversion efficiency, so that the transmission efficiency can reach more than 60%. However, at present, the technical foundation of this kind is weak, and the cost of making photovoltaic arrays with special shapes alone is high, so it cannot be popularized in large quantities.

3.2. MPPT Techniques

At present, one of the reasons why LPT technology is difficult to spread is its low transmission efficiency. According to model analysis, PV cells often fail to work stably due to changes in temperature, optical power, and wavelength. This results in a large amount of energy loss. The solution is to use the Maximum Power Point Tracking (MPPT) system [5].

Prior to this, the MPPT system has been widely used in other photovoltaic cell fields, which can detect and change the voltage and current characteristics of the output of the photovoltaic array, so as to maximize the output power of the photovoltaic cell. Its basic astructure is shown in Fig 5:

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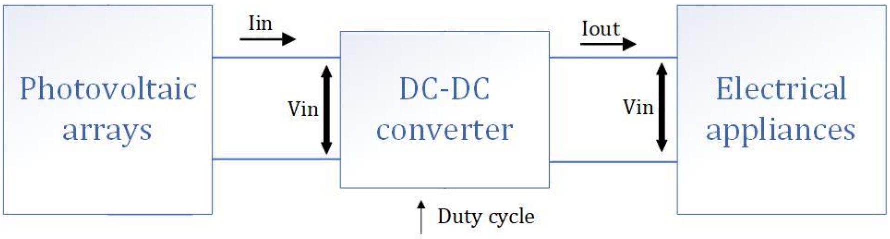

Figure 5. The basic structure of the MPPT techniques

The system adjusts the output characteristics of the circuit in the DC-DC converter through algorithms, and controls the output voltage by changing the duty cycle of the output voltage to achieve maximum power output.

In the case of power matching, the photoelectric conversion efficiency of the LPT system will reach the maximum value, but it is difficult to achieve the matching power in daily use. Through the control of the MPPT system, the energy utilization of the photocell reaches 99.93% when the power is matched, and the overall efficiency is about 10% higher than that before the MPPT system is used.

However, due to the Gaussian distribution of illumination, conventional MPPT systems may fail in the event of multimodal conditions. To solve this problem, a Global Maximum Power Tracking (GMMPT) system can be used to search for the full range of peaks, but this method is time-consuming and needs to be refined [6].

3.3. Secondary Concentrator

At present, the receiver of LPT system usually adopts the method of photovoltaic cell tiling or primary concentrating. For long-distance energy transfer, the uneven distribution of laser spots can lead to difficulties in the layout and design of photovoltaic cells. At the same time, at long distances, the spot size is larger, which increases the demand for photovoltaic cell area. A concentrated light can effectively improve the above situation, but it still produces a large circular light spot, which does not match well with the square photovoltaic cells.

The secondary concentrator system is divided into hollow concentrator and solid concentrator. Hollow concentrators mainly focus light by reflecting light through a reflective film on the inner wall, while solid concentrators concentrate light through the refraction effect of glass. According to the principle of edge light, all the light can be concentrated within a specified range.

Compared with the primary concentrating, the photoelectric conversion efficiency of the secondary concentrating is increased by 6%-7%. After accounting for the energy loss in the secondary concentrating process, the conversion efficiency is also increased by 2%-3% [7].

4. Conclusion

As a new field of wireless energy transmission, LPT technology can supply power to high-altitude motion machines such as drones and spacecraft, and has a wide range of application prospects. However, at present, the backwardness of technology and transmission efficiency have hindered the application of this technology. Compared with the traditional wireless charging method, LPT technology has the advantages of longer transmission distance, small receiver diameter and sensitivity. At the same time, its low transmission efficiency is also the reason why LPT technology is difficult to popularize.

At present, the improved geometry of photovoltaic panels, MPPT technology, and secondary concentrating technology can effectively improve the energy transmission efficiency of LPT technology. For changing the shape of the whole photovoltaic column, this method is currently in the early stage of development due to its low conversion rate and high cost, but theoretically the technology has high transmission efficiency and good development prospects. MPPT technology has been used in a number of photovoltaic fields, and the technical foundation is good, but for LPT technology, under the condition of uneven irradiance, there may be a failure phenomenon, so the GMMPT system can be adopted, and at the same time, it can also be combined with the above-mentioned photovoltaic array shape change technology to enhance stability. Secondary concentrator technology also requires the use of specially made instruments, which has low applicability, and the transmission efficiency improvement is not as obvious as that of MPPT systems. However, there is no need to consider the incident ray spot and energy distribution, and higher light concentrator technology can be developed in the future.

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