Design of flyback power supply of DC equipment in PV power plant

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Abstract. In photovoltaic (PV) grid-connected power generation systems, the needs of low-voltage DC power supply for equipment in PV power plant areas are common. This article provides a design of wide-range high-input voltage flyback power supply. Firstly, the needs of the input voltage range are analysed, and the power supply indexes are defined. Then, the design of the power supply and the transformer circuit are given. The prototype trial results are also given at the last. The results show that the designed power supply meets the requirements of equipment in PV power plant.

1. Introduction
In the PV grid-connected power generation system, digital devices, such as smart DC combiner boxes and surveillance cameras installed in the PV field, require low-voltage DC power supply. With the development of PV applications, the cost of PV electricity has been lower than the price of industrial electricity. It is an economic and convenient way to directly use PV power to power the equipment in the PV field. The flyback power supply based on PV direct current has high application value.

For the power converter has a high voltage main power input and a low voltage backup battery output, the integrated flyback power converter is designed for the uninterruptible power supply (UPS) in [1]. The flyback power converter strategy is utilized in the design for subsidiary equipment in PV system. A multiple output isolated flyback switching power supply with TOP258 power chip is designed for as auxiliary power for PV inverter which show the highly efficiency [2]. The transformer principles of the flyback switching power supply is the core part of the circuit design [3]. For the conversion efficiency and system reliability, the adaptive modulation scheme and the technology of flyback circuit are proposed [4, 5].

And this kind of power supply is different from the conventional flyback power supply, especially the input voltage range is larger [6]. In response to this kind of the actual engineering needs, a DC flyback power supply of PV is designed in this paper.

2. Power supply technical indicators

2.1. The power supply input voltage range
Among the PV module limit parameters, the maximum system voltage is 1500V DC. In the PV grid-connected power generation system, usually PV modules are used in series, and the PV module string
voltage should not exceed the maximum system voltage of 1500V DC. Determine the input withstand voltage of the flyback power supply to be 1500V DC. The ratio of the open-circuit power supply of the PV module to the output voltage of the maximum power point is 1:0.8. According to this relationship, the maximum working input voltage is determined to be 1200V DC. The minimum value of the flyback power supply input voltage can be considered based on the PV module string voltage direct inversion and chopping to 220V AC. At this time, the minimum value of the PV module string voltage is the peak AC voltage of 311V, and the minimum value of the selected flyback power supply input voltage is 200V DC.

2.2. The power supply technical indicators
Determine the power supply technical indicators as follows in Table 1:

| Technical indicators                  | Value   |
|---------------------------------------|---------|
| Input withstand voltage               | 1500V   |
| Maximum working input voltage         | 1200V   |
| Minimum working input voltage         | 200V    |
| input power                           | 250W    |
| Output Power                          | 200W    |
| The output voltage                    | 24V     |
| Output current                        | 8.4A    |
| Output ripple voltage                 | 100mV   |
| Operating frequency                   | 65kHz   |

3. Circuit design of the power supply and transformer

3.1. Design of power circuit and flyback transformer
The power circuit is shown in the Figure 1. The input DC filter power supply is considered in accordance with the input withstand voltage value of 1500V, and electrolytic capacitors C1~C4 with a withstand voltage of 400V are selected for filtering in series, and each capacitor is connected in parallel with balancing resistors R1~R4 to equalize the voltage. Considering the maximum working input voltage of 1200V, switching transistor Q1 selected 1500V the MOS switch. According to the load and heat dissipation of the MOS switch MOS transistor current, the rated current is selected as 9A. The primary leakage inductance current absorption circuit of the flyback transformer is composed of diode D1, resistor R6, capacitor C5 and transient suppression diode TVS1. The transient suppression diode TVS1 functions as a voltage clamping diode, and the absorption circuit functions as a protection switch MOS transistor Q1 effect.

In the case that the switch MOS transistor Q1 withstand voltage value is selected, the design of the flyback transformer ratio $N_p \cdot N_s^{-1}$. The voltage safety margin of the switching MOS transistor Q1 is 130V, and the clamping voltage VZ of the clamping diode TVS1 is 170V. When the maximum working input voltage is 1200V, the maximum voltage across the switching MOS transistor Q1 is 1400V. The clamping voltage Vz of TVS1 is the best 1.4 times of the reflected output voltage V or (the reflected output voltage) of the flyback transformer [7], and Vor is determined to be 120V. The secondary winding voltage Vsec of the flyback transformer is the output voltage of the power supply 24V plus the estimated value of the loop voltage loss of 1V, which is 25V. Based on this, it is determined that $N_p \cdot N_s^{-1} = \frac{Vor \cdot Vsec^{-1}}{1V} = 4.8$. 
According to the switching frequency of the power supply, the core material of the flyback transformer should be PC40 or similar ferrite material. Further select the core size according to the area product method [8]. Calculated as follows:

$$AeAw = \frac{2\cdot Po\cdot \sqrt{D}}{\eta \cdot Kw \cdot J \cdot \Delta B \cdot f}$$  \hspace{1cm} (1)

Among them, AeAw is the magnetic core area product, which represents the product of the effective cross-sectional area of the magnetic core Ae and the magnetic core area window Aw; Po is the output power of the power supply, where the value is 200W; D represents the maximum duty cycle, according to the output reflected voltage Vor and work. The minimum value of the input voltage is calculated as 0.375; \(\eta\) represents efficiency, which is estimated to be 80% here; Kw represents the ratio of the coil to the core window area, which is estimated to be 0.3 here; J represents the current density, which is taken here as \(4 \times 10^6 \text{A} \cdot \text{m}^{-2}\); \(\Delta B\) represents the change in magnetic flux density of the magnetic core, and the value here is 0.1T; f represents the switching frequency, and the value is 65000Hz here. After calculation, AeAw is equal to 3.925cm². The EER4215 core AeAw=4.36cm², which is determined to meet the requirements of use after trial production.

The formula for calculating the number of turns of the primary coil of the flyback transformer is as follows:

$$Np = \frac{Vin \cdot D}{Ae \cdot \Delta B \cdot f}$$  \hspace{1cm} (2)

Among them, the value of Vin is 200V, and the others are the same as the above formula. 64 turns of the primary coil are calculated. Calculate 14 turns of the secondary coil based on the turns ratio. According to the voltage ratio between the secondary winding and the auxiliary winding, it can be calculated that the auxiliary winding turns are 11 turns.

When the switching power supply is at the minimum operating input voltage, the flyback transformer works in continuous mode. At this time, the average conduction current \(I_{av}\) of the switch MOS transistor during the conduction period is calculated, as shown in the following formula [7].

$$I_{av} = \frac{Po}{\eta \cdot D \cdot Vin}$$  \hspace{1cm} (3)

During switch conduction, the flyback transformer primary winding inductance role play, applied to primary winding inductance \(L_p\) voltage so that the conduction current is increased, the primary inductance \(L_p\) storage. The ratio of the increase in the conduction current of the switch MOS transistor to the average conduction current of the switch MOS transistor is the current ripple rate \(r\) [7]. The design value of \(r\) is 0.8. According to the balance between the energy storage of the primary inductance \(L_p\) and

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**Figure 1.** Power circuit of flyback transformer.
the output power of the switching power supply, the primary inductance Lp can be designed and calculated. The specific calculation formula is as follows:

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L_p = \frac{2 \cdot P_o}{\eta \cdot f \cdot I_{av}^2 \left(1 + \frac{r}{2} \right)^2 - \left(1 - \frac{r}{2} \right)^2}
\]

After calculation, the primary inductance Lp is designed to be 430uH. According to this primary inductance Lp, the air gap can be adjusted during the manufacture of the flyback transformer so that the measured value of the primary inductance reaches the design value.

3.2. Control circuit design

This power supply selects the current type PWM control chip OB2269. The start-up current of OB2269 is as low as 4uA, and the working input voltage of this power supply is as high as 1200V, which can effectively reduce the start-up circuit loss. Light load load or no at for condition condition, the extended the ic operates in ‘burst mode’ to minimize switching loss. Standby the lower power conversion efficiency and in areas of communications is thus achieved. The power supply control circuit as in Figure 2.

![Figure 2. Schematic diagram of power supply control circuit.](image)

The starting circuit is composed of R1–4 and TVS diodes. The resistors R1–R4 of the same specification are electrically connected in series to meet the power supply withstand voltage requirement of 1500V, and the TVS diode plays a role of voltage stabilization. The parameter design of the resistors R1–R4 and TVS is based on meeting two requirements: when the working input voltage is the minimum, the resistor current flowing through R1–R4 can start the power supply within the specified time; when the working input voltage is the maximum, flowing through R1–4. The resistance current is as small as possible to reduce the loss of the starting circuit.

The operating frequency of the PWM control chip OB2269 is the power switching frequency. The resistance value of the resistor R17 connected to the 4-pin of the chip is designed to determine that the power switching frequency is 65kHz. The 8-pin GATE of the PWM control chip OB2269 is connected to the DRV_G signal end of the power circuit of the power supply through a resistor R15 to drive the MOS switch to turn on and off. The 6-pin SENSE of the PWM control chip OB2269 is connected to the Isense signal end of the power circuit of the power supply through R16 to measure the peak current flowing through the primary winding of the flyback transformer. The NTC resistor connected to the chip's 5-pin RT sets the operating temperature of the power supply. When the power supply temperature exceeds the value, the NTC resistor's resistance becomes smaller, and then the voltage of the chip's 5-pin RT is lowered. The PWM control chip OB2269 stops PWM output and the power supply stops output.
The feedback compensation circuit is mainly composed of the opt coupler chip PC817 and the voltage reference TL431. The 4-pin of the opt coupler chip U3 is connected to the 2-pin FB of the PWM control chip OB2269. The parameters of resistors R18–R20, RF and capacitor CF can be designed according to the method in [9].

In order for the power supply to work safely, it must have input over-voltage protection. Input voltage exceeds 1200VDC, the off stop PWM output, the power supply is stopped. The input over-voltage protection circuit is mainly composed of the voltage reference TL431. The resistors R5–R8 and R9 form a resistor divider and the voltage signal is connected to the reference pin of the voltage reference TL431. When the input voltage exceeds 1200V DC, the cathode potential of TL431 drops, and the base of PNP transistor Q1 is pulled down through resistor R11. Transistor Q1 is turned on to inject current into the base of NPN transistor Q2, transistor Q2 is turned on, and OB2269 is pulled down through diode D1. With the potential of the 5-pin RT, the PWM control chip OB2269 stops the PWM output and the power supply stops working to achieve the purpose of input over-voltage protection.

4. Prototype of the designed power supply
According to the above design scheme, a 200W flyback power supply is produced and tested. Under the 320V DC input voltage, the electronic load is adjusted to make the power supply output power of 14.6W, and the measured power supply input power is 15.95W. The oscilloscope observes and exports the drain voltage waveform of the switch MOS transistor under light load as shown in the figure below. From the figure, it can be estimated that the switching frequency is 25KHz, and the efficiency is 91.5% at this time, which verifies that the power supply has good efficiency even under light load.

Under the 320V DC input voltage, the electronic load is adjusted so that the output power of the power supply is 202W, and the measured input power of the power supply is 248.82W. The oscilloscope observes and exports the drain voltage waveform of the switch MOS transistor under light load and full load as shown in the Figure 3 to Figure 5. From the figure, it can be estimated that the switching frequency is 66KHz, and the efficiency is 81.1% at this time, which verifies that the power supply reaches the design efficiency at full load.

![Figure 3. Prototype of the designed power supply.](image)

![Figure 4. Drain voltage of switch MOS transistor at light load.](image)
5. Conclusions
This paper designs a PV flyback power supply with an input operating voltage range of 200-1200VDC and an output power of 200W, and provides the design of the main circuit and flyback transformer. The prototype trial production results show that the designed power supply meets the low-voltage DC power supply requirements of the equipment in the PV field area of the PV grid-connected power generation system.

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