Wide Input Voltage Range Flyback Converter Design with Boundary Conduction Mode

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Abstract. A new design method of flyback switching power supply is proposed for wide input voltage application. The new design method is called the boundary conduction mode (BCM) design.The finished flyback converter can operate in very wide input voltage from 80V to 500V reliably with the proposed method. The procedure of the transformer design is shown. And a 15W prototype with the new design method is developed. The experiments results show that the proposed converter can operate in the discontinuous conduction mode(DCM), BCM and the continuous conduction mode(CCM) with 12V output voltage and 15W output power. The experiments also show that the new flyback converter is suitable for very wide input voltage applications.

I. Introduction

Growing caring about our living environment have led to increased interest in clean energy resources such as photovoltaic(PV) array, wind generator, fuel cell and so forth. When energy demand around the world increase, the demand for the renewable energy source that will not harm the environment has never been greater. Some institutions predict that the global energy demand will almost triple by 2050. Using solar energy is one way to meet the need, converting sunlight directly into electricity with no moving parts and no harmful pollution. Although more conventional sources of energy, such as fossil fuels, are still satisfying the majority of the world's energy demand, solar energy systems are used in a great variety of applications. These applications may be grouped into two categories: utility interactive systems and stand-alone systems or three categories: DC-solar system, AC-solar system, AC and DC hybrid solar system.

The DC-solar system is a good solution for the remote areas. Where power demand is small and a stand-alone system is needed. Particularly in areas where there is not an existing utility power, and the sunshine is enough, The solar energy can provide reliable power for DC appliances such as lights, radio, TV, fans, pumps and security systems.

Many PV modules are connected in series to obtain sufficient dc input voltage in conventional PV array system uses. However, technical problems is encountered in avoiding shadows created by neighboring buildings, utility poles, trees, and other obstacles that may partially cover some of the PV modules in the array. As a result, the total output power generated from the PV array decreases remarkably[1]. Also, AC module strategy has been researched widely. But the fluctuation voltage is not suitable for the precision equipment. To overcome the shortcomings, the very wide voltage range DC-DC converter is needed in the application of DC-solar system.

However, a conventional DC-DC converter operate in the traditional input voltage range of 3:1. A new design is required if the input voltage is wider than the range of 3:1. This leads companies to develop products targeted at specific marketplaces, which can be costly, or to have their customers arrange jumpers to accommodate their power system which can be annoying or lead to costly errors.

In this paper, a new flyback switching power supply is proposed. It can operate beyond the traditional input voltage range of 3:1 to a range of more than 6:1(80 to 500 Vdc) without affecting the reliability of its operation. This is realized by changing the mode of operation within the wide range input voltage, designing the transformer properly and selecting the control IC.

II. Operation Principle and circuit configuration

Flyback converter topology is very widely used for those applications less than 150 W with the significant advantage of needing no secondary output inductors. The representative flyback converter can be seen in Figure 1. It can operate in the discontinuous conduction mode(DCM) or the continuous conduction mode(CCM) mainly[2]. For some very wide input voltage applications, the converter can operate in the hybrid mode according to the input voltage[3-4].

When the current of D has not fallen to zero at the end of the off time, the current of S at the next turn on will have a front-end step as the current in an inductor can't change instantaneously. Currents in S and D all have a characteristic ramp-on-a-step waveshape. Ignoring the on-state voltage, the equation (1) can be obtained according to the law of volt-second balance.

$$V_{dc(\min)}t_{on(\max)} = V_{out}N(T - t_{on(\max)}) \tag{1}$$

Where, $V_{dc(min)}$ is minimum input voltage, $T_{on(max)}$ is maximum turn on time, T is the period ,N is turns ration and V_{out} is the output voltage.Then,

$$V_{out} = \frac{V_{dc(\min)}}{N(T/t_{on(\max)} - 1)} \tag{2}$$

It is known that the feedback loop regulates against DC input voltage changes by decreasing T_{on} as V_{dc} increases, or increasing T_{on} as V_{dc} decreases. When the input voltage increases obviously, the T_{on} is so small that the current of D will fall to zero at the end of the off time. Then the operation will change to the discontinuous conduction mode (DCM). Therefore, the flyback converter can operate over a very wide input voltage range with the hybrid operation mode.

According to the above principle, this paper reviews one method of enabling a flyback converter to operate beyond its traditional range of input voltage of 3:1 to a range of more than 6:1 without affecting the reliability of its operation. This is done by designing the converter with the boundary conduction mode(BCM) and then the converter can change its mode of operation with the change of the input voltage.

Using the current mode PWM controller UC2845 as control IC, the circuitry is simple and the converter can operate from -25℃ to 85℃. With the help of the new design, the converter can operate in both DCM and CCM with the stable dynamic performance.

III. Design procedure of proposed flyback converters

The wide−input range flyback converter described has the following specification shown in Table 1,where Vin is the input voltage, Vo is the output voltage, Po is the output power, fs is the switching frequency and η is the efficiency.

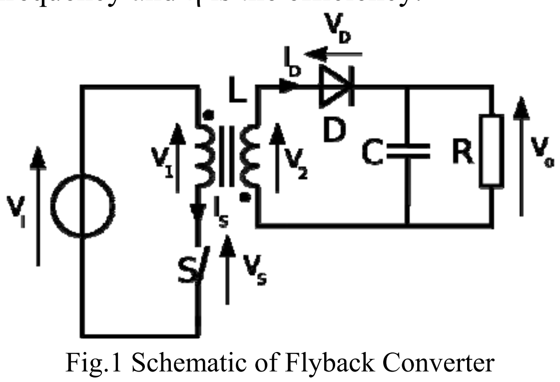

Fig.1 Schematic of Flyback Converter

Table 1 Proposed flyback converter specification

Parameters	Value
V_{in}	80-500V
V_o	12V
P_o	15W
f_s	70k
η	80%

The transformer must be designed properly to make the flyback converter operate in both DCM and CCM. So the transformer design is the key step. The detailed design procedures are as follows:

A.Turns ration calculation

First, the maximum duty cycle Dmax can be supposed as 0.45 with the minimum input voltage. According to the law of volt-second balance, the following equation can be obtained.

$$\boldsymbol{V_{dc(\min)} \times D_{\max} = V_r \times (1 - D_{\max})} \tag{3}$$

Where Vdc(min), Dmax and Vr are the minimum input voltage, the maximum duty cycle and the output voltage reflected to the primary ,respectively. The value of Vr would be 65.5V through calculation. The value of turns ration N would then be :

$$\boldsymbol{N} = {}^{N_P}\!/_{N_S} = {}^{V_r}\!/_{(V_o+V_s)} = {}^{65.5}\!/_{(12+0.7)} = \mathbf{5.16} \tag{4}$$

Where Np and Ns are the number of turns for primary side and secondary side, respectively.

With the obtained value of N, the maximum reverse voltage(Vd(max)) of output diode can be calculated as following:

$$\boldsymbol{V}_{d(\max)} = {}^{V_{in(\max)}}\!/_{N} + \boldsymbol{V}_o = \mathbf{108.9} \tag{5}$$

Generaly, the power devices should have some margin for them to work safely. So we can select 120V or 150V diode for the design Flyback converter.

B. Estimation the inductance of the primary side

To make the converter operate in the hybrid mode, we design the transformer using the boundary conditions. In this paper, the very vide input voltage is from 80V to 500V. We select 200V as boundary voltage to design the transformer. The name boundary conduction mode(BCM) comes from the fact that the controller operates right on the boundary between CCM and DCM. In other words, the switch turns on and stores just enough charge to replenish the load during the time the switch opens. Thus the switch turns on again as soon as all the energy is transferred to the output. The controller ensures that there is very little time when the transformer has no energy stored as flux, known as dead time.

According to the law of volt-second balance, the following equation is established:

$$\boldsymbol{V}_{bcm} \times \boldsymbol{D}_{bcm} = \boldsymbol{V}_r \times (1 - \boldsymbol{D}_{BCM}) \tag{6}$$

So Dbcm=0.35. Where Vbcm is the boundary voltage and Dbcm is the boundary duty cycle.

Calculating the primary inductance needed for this converter:

$$\boldsymbol{L}_{bcm} = {}^{(V_{bcm}\times D_{bcm})^2}\!/_{2\times P_{in}\times f_s\times K_{rf}} = \mathbf{1.74}\ \text{mH} \tag{7}$$

where Vbcm is boundary voltage, Dbcm is boundary duty cycle, Pin is input power, fs is the switching frequency of the proposed converter device and Krf is the ripple factor in full load and minimum input voltage condition. For DCM and BCM operation, Krf = 1 and for CCM operation Krf < 1. The ripple factor is closely relatedwith the transformer size and the RMS value of the MOSFET current. Even though the conduction loss in the MOSFET can be reduced through reducing the ripple factor, too small a ripple factor forces an increase in transformer size. When designing the flyback converter to operate in CCM, it is reasonable to set Krf = 0.25-0.5 for the universal input range and Krf = 0.4-0.8 for the European input range.

C. Determine the turns of the primary and second side

According to the output power, we select EE19L as the core with the material of ferrite (PC40). With the chosen core, the minimum number of turns for the ransformer primary side to avoid the core saturation is given by

$$\boldsymbol{N}_{p(\min)} = [{}^{V_{in(\max)}\times D_{\min}}\!/_{f_s\times A_e\times B_{\max}}]\times 10^3 = \mathbf{159}\ \text{turns} \tag{8}$$

where Vin(max) is the maximum input voltage, Dmin is the minimum duty cycle, fs is the switching frequency, Ae is the cross-sectional area of the core and Bmax is the saturation flux density in tesla.

The value of Np was put into the equation(4).Then, the value of Ns will be 31turns.

Through the above calculation, the final transformer parameters have been determined. The actual parameters can be corrected by experiments.

IV. Results and discussion

A 15W proposed Flyback prototype has been filished according to the determined parameters. Experiments have been done on the prototype with vide input voltage from 80V to 500V. Primary Current experimental results are shown in Fig.2,Fig.3,Fig.4, respectively for 80V input voltage, 200V input voltage and 500V input voltage. From them, we can know that the converter works in CCM when the input voltage is 80V, in BCM when the input voltage is 200V and in DCM when the input voltage is 500V. The duty cycle are 44.47%, 20.18%, 0.34%, respectively for 80V input voltage, 200V input voltage and 500V input voltage, which are in consistent with the above design and calculation.

Fig.5 shows the output voltage waveform. It shows that the output voltage is about 12.04V with input voltage from 80V to 500V. Also, the 15.5W output power and 82% efficiency can be get through the test.

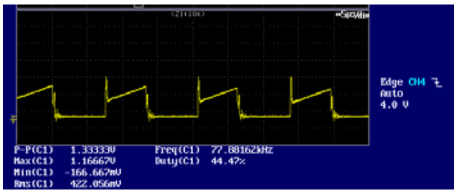

Fig.2 Primary current waveform with 80V input voltage

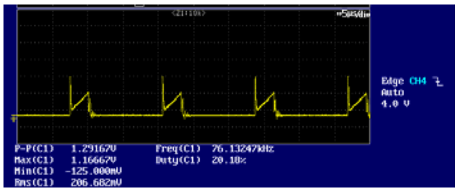

Fig.3 Primary current waveform with 200V input voltage

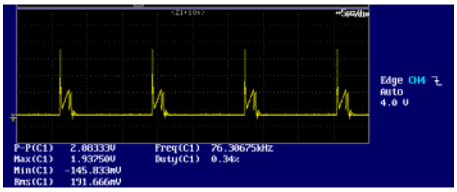

Fig.4 Primary current waveform with 500V input voltage

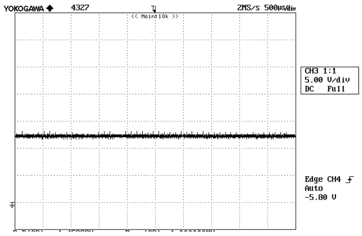

Fig.5 Output voltage waveform

V. Conclusion

This paper proposed an effective and useful design method of flyback switch power supply for PV application. The new design method of transformer with BCM make the designed converter work reliably in the very wide input voltage from 80V to 500V. The prototype with output power 15W was developed. The test results show that the proposed method is effective. This provides a new idea for wide input voltage flyback switching power supply design.

Acknowledgments

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References

[1] Huang-Jen Chiu, Chun-Jen Yao and Yu-Kang Lo. A DC/DC converter topology for renewable energy systems[J].International Journal of Circuit Theory and Applications,37(3):485-495,2009.

[2] J.I. Castillejo, M. Garcia-sanz. Robust control of an ideal DCM/CCM flyback switching converter. MED,2002.

[3] V. Kenia Mayur. Development of an isolated flyback converter employing boundary-mode operation and magnetic flux sensing feedback [D]. the department of electrical engineering and computer science, Massachusetts institute of technology, 2004.

[4] Marty Brown. Very wide input voltage range off line Flyback switching power supply. Onsemi application note:AN1327/D.