Design A High Efficiency Auxiliary Power Supply with Wide Input Voltage Range for PV-PCS

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Abstract

In high power PV generation system, the solar cell normally generates wide output voltage depending on the insolation, cell's temperature and shade effect. This paper will propose a high efficiency converter allowing the wide input voltage to supply stable voltage with the controller and operation for the PV generation system. The proposed converter consists of two stages comprising SEPIC with a coupled inductor and LLC, which generates 24 V of output at the final output terminal. In this paper, a design method and experimental results with a test-bed of 50 W will be presented to validate the proposed converter.

1. Introduction

A normal structure of PCS for photovoltaic power generation consists of two types of power converter. One is a dc-dc converter where a boost converter is mainly used and another is an inverter to convert a dc output voltage from the boost converter to an ac voltage used as the commercial electricity. Meanwhile an auxiliary power converter is necessary to supply operating power to the controllers as shown in Figure 1.[1] The output voltage of a solar cell varies depending on the environment, e.g. for a 900 Vdc module, it may fall down to under 200 Vdc. Fly-back converters are mainly used in such a wide input auxiliary power converter, but, this topology has drawbacks in low efficiency and difficulties in optimal design for wide input range. [2] [3]

This paper proposes a two-stage auxiliary power converter consists of SEPIC(Single Ended Primary Inductor Converter) with a coupled inductor and LLC resonant converter, which can operate in a wider input range(100 Vdc – 900 Vdc) compared to fly-back converters.

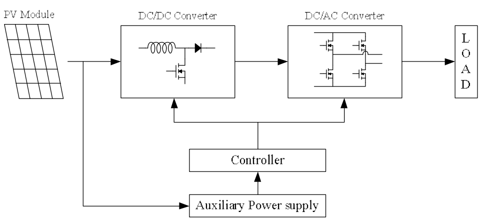

Fig. 1 Block diagram of PV PCS

2. High efficiency power converter design

2.1 The proposed converter

Figure 2 shows the schematic of the proposed converter which operates under a wide input range. The proposed converter consists of two stages comprising SEPIC with a coupled inductor and LLC resonant converter for providing high-efficiency and stable operation even in a wide input range. In the first stage, SEPIC generates constant output voltage of 250 Vdc and supplies it to LLC resonant converter. Resonant converter in the second stage generates 24 Vdc low output voltage and supply it to the controllers of the main power converter. It is easy to implement multiple outputs without any linear regulator because of its good cross regulation characteristics.

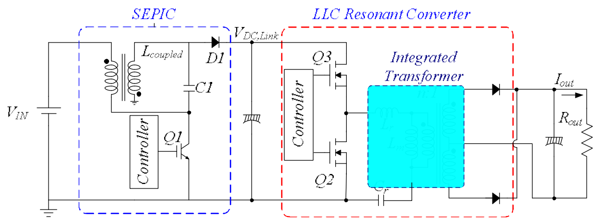

Fig. 2 Schematic of the proposed dc-dc converter

2.2 Main components design

2.2.1 SEPIC with a coupled inductor

The gain for CCM operation is:

$$M = \frac{V_O}{V_{in}} = \frac{D}{1-D} \tag{1}$$

The gain for DCM operation is:

$$M = \frac{V_O}{V_{in}} = \frac{D}{n\sqrt{2L_{coupled}/(RT_s)}} \tag{2}$$

The coupled inductance in SEPIC in which energy is stored can be obtained as follows:

$$L_{coupled} = \frac{(V_{in,\min} \times D_{MAX})^2}{2 \times P_{in} \times f_{sw} \times K_{RF}} \tag{3}$$

It is possible to design the coupled inductor with Equation (3) to operate either in CCM or DCM operation according to different input power utilizing K_{RF}, where K_{RF} is defined as in Figure 3.

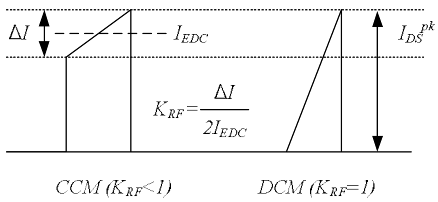

Fig. 3 Definition of K_{RF}

2.2.2 LLC resonant converter

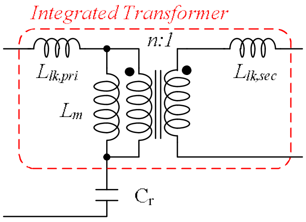

Fig. 4 Equivalent circuit of integrated transformer

Figure 4 shows the equivalent circuit of integrated transformer. The gain of LLC resonant converter is as below:

$$M=\frac{2n\cdot V_o}{V_{in}}=\frac{\left(\omega/\omega_r\right)^2(m-1)}{\sqrt{\left[\left(\omega/(\omega_r\omega_s)\right)^2(m-1)+1-\left(\omega/\omega_p\right)^2\right]^2+\left[\left(\omega/\omega_r\right)(m-1)Q\left(\left(\omega/\omega_r\right)^2-1\right)\right]^2}} \quad (4)$$

The definitions of the parameters are:

$$L_P=(L_{lk,pri}+L_m), L_r=(L_{lk,pri}+(L_{lk,pri}\parallel L_m), m=L_p/L_r$$

$$\omega_r=\frac{1}{\sqrt{L_rC_r}}, \omega_p=\frac{1}{\sqrt{L_pC_r}}, \omega_s=\frac{1}{\sqrt{L_rC_s}}, Q=\frac{1}{R_{ac}}\sqrt{\frac{L_r}{C_r}}, R_{ac}=\frac{8n^2V_o}{\pi^2 I_o}$$

The main components for resonance (L_P, L_r and C_r) can be obtained as follows:

$$C_r=\frac{QR_{ac}f_r}{2\pi},\ L_r=\frac{C_r}{(2\pi\times f_r)^2},\ L_p=m\times L_r \quad (5)$$

3. Experimental results

The key parameters' values for the proposed converter are shown in table 1.

Table 1. Key parameters' values

SEPIC		LLC Resonant Converter	
Parameter	Value	Parameter	Value
Switching Frequency	15 [kHz]	Operating Frequency	100 [kHz]
$L_{coupled}$	4.5 [mH]	L_P	675 [uH]
C1	330 [nF]	L_r	75 [uH]
		C_r	33 [nF]

The basic operation and main waveforms for the SEPIC and LLC resonant converter are shown in Figure 5 and Figure 6, respectively. The test conditions are: the input voltage of SEPIC is 400 Vdc, the output voltage of LLC resonant converter is 24 Vdc and 50 W of load is applied. The maximum efficiency of the auxiliary power converter is 80%.

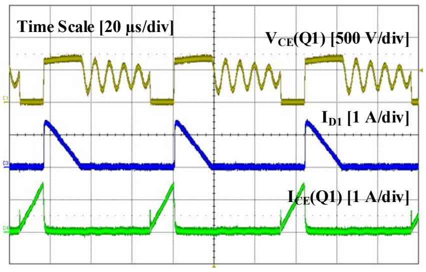

Fig. 5 Key waveforms in SEPIC converter
(From top to bottom, V_{CE} of Q1, current of D1 and current of Q1, respectively. V_{IN}=400 Vdc)

As can be seen in Figure 5, the voltage across switch Q1 is clamped to the input voltage without any voltage spike.

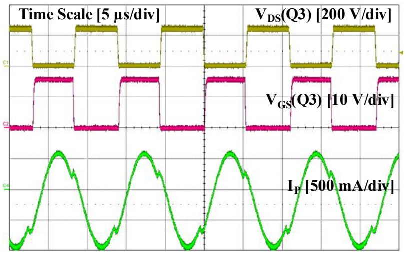

Fig. 6 Key waveforms in LLC converter
(From top to bottom, V_{DS} of Q3, V_{GS} of Q3 and input current of transformer, respectively. $V_{DC,Link}$= 250 Vdc)

In Figure 6, it can be seen that the main switch(Q3) and auxiliary switch(Q2) of the LLC resonant converter are operating in ZVS region. The waveform of the primary current is almost sinusoidal which shows that the LLC converter is operating nearly at the resonance frequency.

4. Summary

This paper proposed a two-stage auxiliary power converter consists of SEPIC with a coupled inductor and LLC resonant converter with a wide input voltage range of 100 ~ 900 Vdc. It presented the design method for the parameters of the main components by the basic operation of SEPIC and LLC resonant converters. A test-bed of 50 W is designed to validate the proposed converter. It's evaluated that the proposed converter operates properly under a wide input voltage range and the maximum efficiency is over 80%.

References

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