Interleaved Flyback DC-DC Converter Design with 350 W Power Output Using LT 3757 in LT Spice

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Abstract. DC-DC converter becomes one important part in micro-inverter used in solar panel application. Its function is to convert output voltage level of solar panel 42-48 V_{dc} to a voltage level of 350 V_{dc} before being converted into an AC voltage at the inverter. The proposed converter topology is a flyback because the number of components used is not too much which can suppress the production cost. In this paper, simulation of flyback converter on the interleaved operating mode with a maximum output power of 350 W using software Ltspicewas conducted. From the simulation results, obtained that by applying a switching frequency of 100 kHz, the obtained value of the components of the primary inductor (L_P) 3.3 μH, the secondary inductor (L_S) 27 μH, the output capacitor (C_{out}) 47μF and ripple voltage (V_r) 212.65 mV.

1. Introduction

Solar panel (photovoltaic) is used to convert solar radiation into anelectrical energy source. Micro-inverter (dc-ac power electronics converter) is an important component of thesolar panel system. Micro-inverter in photovoltaic conversion is a part of theinfrastructure that converts the power generated from photovoltaic panels into AC that can be transmitted to a network. There are three types of conventional inverter architecture: central inverter, string inverter, and micro-inverter [1][2]. Some researches on photovoltaic micro-inverter have been widely developed since micro-inverter can be directly applied in photovoltaic panel producing energy. Several other advantages of themicro-inverter system include: increasing reliability of the system, improve efficiency and reduce the cost[3].

Micro-inverter system can be implemented using two methods *i.e.* single power stage and dual power stage[4]. This research is focused on dual power stage method in the dc-dc converter topologies flyback. This dc-dc converter is highly important as it changes dc signal from thesolar panel into dc signal with a higher voltage. There are several ways to convert dc signal to a higher dc signal, using a flyback converter is one of them[3]. Flyback converter uses high-frequency transformer which is lighter and has asmaller size than lower frequency transformer, and it is also more efficient because it has asmaller size. Therefore, the overall shape of flyback converter is compact. This study provided the simulation of interleaved operating mode using Lt spice and LT 3757 as PWM controller, with a maximum power output of 350 W. The simulation results were then compared to the previous literature reviewed and it obtained 3.3 μH of primary inductor (Lp), secondary inductor (Ls) 27 μH, the output capacitor (Cout) 47 μF and ripple voltage (Vr) 212 mV.

2. Methods

2.1. Interleaved Flyback DC-DC Converter Circuit Design

Basic topology of the flyback dc-dc converter is shown in Figure 1. It consists of several parts: the input voltage from thesolar panel, high-frequency transformers, electronic switch, and capacitor filter that serves reduction of output voltage ripple.

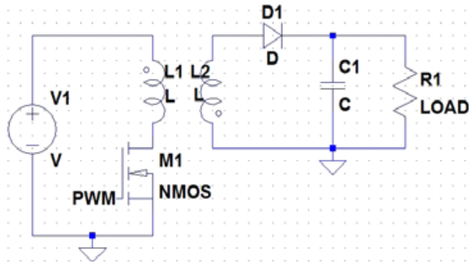

Figure 1. Topology Flyback Converter.

Input voltage from the solar panel to the flyback converter using a solar panel was adjusted to the sun module SW XL 340-350 MONO data sheet, which was 42-48 V with a power of 350 W. The interleaved flyback DC-DC converter circuit used LT 3757 as the PWM controller. PWM controller used as the electronic switch was MOSFET. MOSFET used in this research was Si7850DP with switching frequency of 100 kHz. This interleaved circuit changed the input DC voltage from the solar panel into a higher DC voltage through the switching process and thefeedback voltage from the output voltage. The activation of MOSFET was controlled by signals generated from the LT 3757.

This study used operating mode of interleaved flyback converter, as shown in Table 1 that specified the parameters used in the simulation of Lt spice. In this mode, flyback circuits were parallel to double the power of non-interleaved mode, and the output ripple voltage could be reduced due to the different phases when the electronic switch was on or off.

Tabel 1. Specifications of flyback dc-dc converter parameters in LT SPICE simulation

Parameter	Specification
Tegangansumber PV	42 – 48 V_{dc}
Frekuensi	100 kHz
N-Mosfet	Si 7850 DP
Kontrol PWM	LT 3757
DiodaSchottky	MBRS 360
Duty Cycle (D)	2,758 ms
Duty Cycle 2 (D_2)	1,223 ms

2.2. LT 3757

LT 3757 is a dc-dc controller capable of generating positive or negative output voltage with a wide input range. LT 3757 can be configured as flyback, SEPIC, BOOST or inverting converter. The LT 3757 drives an external power N-MOSFET from an internal supply of 7.2 V. In the current-mode architecture, the fixed frequency generates stable operation over a wide range of supply and output voltages. The operating frequency can be adjusted with an external resistor from 100kHz to 1 MHz, and synchronised to an external clock using the SYNC pin. The minimum operating supply voltage is 2.9 V, and the current is less than 1μA. LT 3757 features Soft Start and frequency foldback functions that are used to limit the inductor current during start-up and output short circuit[5].

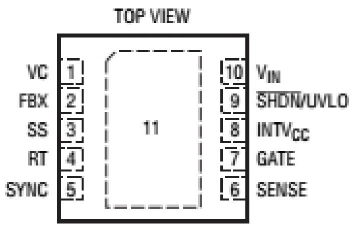

Figure 2.Configuration LT 3757.

2.3. Calculation of Winding Inductor

The process of switching on the circuit flyback dc-dc converter is determined by the signal pulse width modulation (PWM). The working principle is to set the duration PWM on and off electronic switch (t on and t off). The longer the duration of the switch on, the greater the output voltage. The switching process is conducted in a specific switching frequency. A comparison of the switch on the duration of the period known as the duty ratio switching output (Do) as showed by equation (1) [6].

$$D_U = \frac{t_O}{T} \quad (1)$$

The voltage produced by the switching process is then implemented at the high-frequency transformer primary. The transformer will then raise and generates voltage pulse electronic isolation between the input voltage source to the output voltage[7]. The transformer will raise the voltage level by the ratio of the transformer. The dc voltage would be enhanced by the transformer so as to generate dc output voltage is greater. Comparison of the number of winding primary (Np) and secondary (Ns) is equivalent to the ratio of the induced voltage in the primary and secondary transformer [8]. This comparison is called comparison transformer or trans ratio (n), which is also the value of a primary inductor and secondary inductor of the flyback converter transformer can be created by using $\frac{N_P}{N_S} = \sqrt{\frac{L_P}{L_S}} = n$.

The interleaved flyback converter is designed using a high-frequency transformer where can be applied to multiple winding inductors according to the operating frequency factors [9]. The flyback transformer design and calculation requires the duty cycle (D), in which to determine trans ratio (n), it can be calculated using equation (2) where the value of the output voltage (V_{ou}t) = 350 V, the value of input voltage (V_{in}) = 47 V, the value of duty cycle (D) = 2.758 and D2 = 1.223. Thus, the obtained value trans ratio (n) was three.

$$n = \frac{7{,}45}{2{,}255} = 3{,}3 \approx 3 \quad (2)$$

The dc-dc converter can be operated in continuous conduction mode (CCM) and discontinuous conduction mode (DCM), depending on the current of the inductor (iL). The discontinuous conduction mode (DCM) was used in this research, where iL was zero in several parts of the switching period [10]. Transformer design for the DCM operating mode is to improve the working operation; the main switching cycle can be calculated based on the output voltage (V_{out}) and the minimum input voltage (V_{in}). Maximum duty cycle (D_{max}) can be used as the starting point and calculated bythevalue of D_{max} = 0.88.

The used inductor design also depends on the mode of operation used. In the DCM operating mode, the values of primary inductor and secondary inductor on the flyback converter transformer can be determined by using equation (3) and (4), where the value of the maximum duty cycle (D_{max}) and lowest input voltage (V_{min}) are divided by the output power (P_{out}) and the applied frequency (f).

$$L_S = \frac{(0{,}88)^2.(47)^2.1}{2\,.\,350\;100\;10^3} = 24{,}44.10^{-6} \quad (3)$$

$$L_P = \frac{24{,}44\,.\,10^{-6}}{9} = 2{,}715\,.\,10^{-6} \quad (4)$$

From the equation (3) and (4), it was found that the value of L_S = 24.44 µH and the value of L_P = 2.715 µH. Therefore, to approach the actual model in the simulation, the components for L_S was set at 27 µH and L_P was set at 3.3 µH by the components available in the market.

2.4. Output Voltage Calculation

The calculation for theoutput voltage of interleaved flyback converter is conducted to see whether the voltage remains constant even if the load changes because of the increased power. The constant frequency value used to control LT 3757 was set using R (load) which has been developed from the data sheet. With the value of R = 140 KΩ, the frequency generated by time constant was 100 kHz. By Table 1, the output voltage could be determined by using equation (5). The value was customised with LT 3757 configuration in the FBX pin where the internal bias voltage of 1.6 V with voltage divider where the resistance values (R1 and R2) were connected from the value of output voltage to the ground (GND).

$$V_o = 1,6\,V\left(1+\frac{3,5\,m\quad\Omega}{16,074\;K\Omega}\right) = 350\,V \quad (5)$$

2.5. Ripple Voltage Calculation

Ripple voltgae (Vr) of the load is 1% of the desired output voltage (V_{out}). So as to limit the ripple voltage maximum value, the value of the filter capacitance (C) must be higher than C_{out} indicated by equation (6).

$$C_o \geq \frac{1}{0,01\,.\,350\;100.\,10^3} = 2.857\,x\,10^{-6} \quad (6)$$

Thus, Cout should be more critical than $2.857 x 10^{-6}$, as to adjust the capacitors available in themarket then 47 µF was selected. Therefore, the value of ripple voltage (Vr) could be calculated with equation (7), that was the period (T) and the value of used capacitor.

$$V_r = \frac{10\,.\,10^{-6}}{47\,.\,10^{-6}} = 212,65\,m \quad (7)$$

3. Results and Discussion

The simulation was conducted to determine how waveform ofprimary inductor, secondary inductor and voltage ripple (Vr). In this study, circuit simulation using LT 3757 was applied to interleaved flyback dc-dc converter as shownin Figure 3, which was done on the LT spice software. The simulations werecarried out as close as possible to the value of design that has been thoroughly calculated.

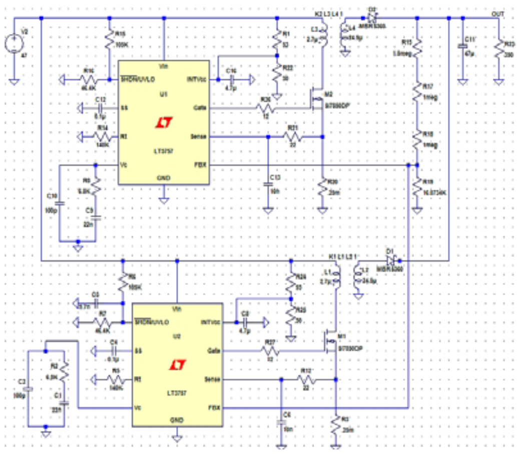

Figure 3. The circuit of interleaved flyback dc-dc converter.

3.1. Results of Transformer Wave

The comparison of thetrans ratio (n) of the transformer winding design was three. In Figure 3, with power load of 350 W, the average voltage primary is 94 Volt and the average current transformer is

36.75 A. Primary transformer voltage is a direct output voltage from the solar panel which is connected directly to the primary inductor (Lp), where if the switching process is ON, the primary winding will be connected to supply. As a result, the flux and the magnet on the primary side are increased and energy stored there in will be transferred. And when the switching is OFF, the magnet and the flux on the primary side is reduced, the secondary inductor generates positive voltage and therefore the diode moves forward. The simulation was conducted in the interleaved operating mode, so it resulted in two different stages of switching ratio as shown in Figure 4.

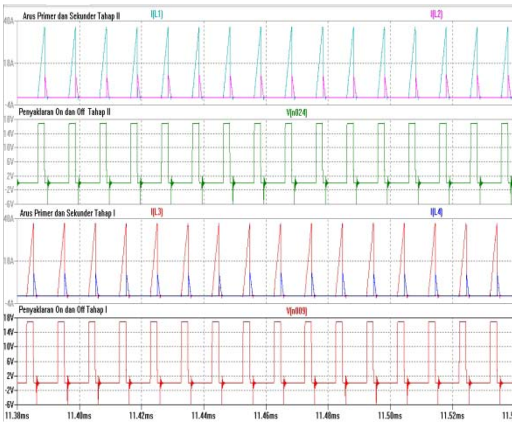

Figure 4. Theswitching process with transformer energy transferring process between primary and secondary sides.

3.2. Output VoltageResults

The desired output voltage in the circuit design of interleaved flyback dc-dc converter is 350 V with varying power load as shown in Table 2. The result of the circuit simulation with the output voltage is 350.73 V the power load of 350 W. The interleaved flyback circuit simulation with the lowest input voltage of 41.5 V and maximum power load of 350 W had a stable voltage at 350.70 V. By using equation (5), it was obtained the desired output voltage in the circuit design of dc-dc converter as 350 V.

Table 2. Results of fixed voltage simulation with varying power load

NO	Tegangan Input (V)	Beban Daya (W)	TeganganKeluaran (V)
1	47	10	350,79
2	47	75	350,76
3	47	100	350,75
4	47	150	350,71
5	47	200	350,70
6	47	250	350,78
7	47	300	350,79
8	47	350	350,70

3.3. Voltage RippleResults

The output ripple voltage of interleaved flyback dc-dc converter could determine the value of capacitor used, which was 47 µF. After mathematically modelling the corresponding data sheet and supporting theories, it was obtained a value of 212.65 mV. Also, the result of simulation performed using LT Spice software was 219.23 mV with anaverage voltage of 350.78 V as shown in Figure 5.

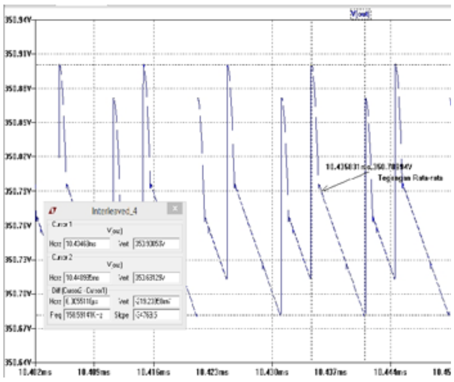

Figure 5. Results of voltage ripple.

4. CONCLUSION

Designing the interleaved flyback dc-dc converter circuit with thepower of 350 W have been exposed. By the specification in Table 1, interleaved flyback dc-dc converter circuit simulation could be used on a stable output voltage of 350.70 V with varying power load as shown in Table 2. When input voltage was at its lowest state (41.5 V) with a maximum power load of 350, the output voltage remained stable at 350.70 V. Therefore; this dc-dc converter design can be combined with an inverter in order to be a complete micro-inverter with dual power stage method.

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