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Implementation of DC-DC Step-Up Converter Design for 200W Off-Grid Microinverter

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Abstract— **In this paper, DC-DC step-up converter design for 200W off-grid solar micro-inverter is discussed. Microinverter system consists of the MPPT section, the DC-to-DC converter section and the inverter section. The MPPT section detects and optimizes the power from the solar panels with the help of PIC microcontroller to achieve the maximum power transfer from the panel at any instant of the time. There are no power storage units such as battery and the DC voltage output of MPPT section is driven to the DC-to-DC converter section, where solar panel DC voltage is inverted to high frequency high voltage AC voltage and then converted into high voltage DC voltage which equal to the peak voltage of the inverter stage output AC voltage. Only a small size soft ferrite core is used as a power converter transformer because of the high switching frequency of about 65 kHz is utilized. The galvanic separated auxiliary low voltage DC for the control circuitry of inverter section is also converted. The final inverter section generates the 50 Hz 230VAC modified sinewave output for the utilities. This is a prototype inverter so that it fabricated on three separate IC strip-boards and these can be combined in a single well-designed compact PCB board. It can be modified up to 1000 VA output power with the modifications of ferrite transformer size and small additional components. The battery-less system provides the green power generating process and environmental friendly.**

Keywords—**MPPT, DC-DC converter, soft ferrite core, inverter, galvanic seperation**

I. INTRODUCTION

There are two important sections in Microinverter System, so called the MPPT section and inverter section. The MPPT section harvest the maximum power from solar panel and the DC output voltage is then delivered to the inverter section. The voltage and current from the PV panel are sensed and the corresponding signals are processed in the PIC 16F877 microcontroller. The output control signal is applied to the FET driver IC, which controlled the switching power MOSFET in the output stage of the MPPT section. The output voltage and current are sensed and applied to the microcontroller inputs, so the program controls the maximum power point of the PV panel. The status lamps are indicated the appropriate conditions.

There are two main groups in inverter section, the DC-to-DC step-up converter and the DC-AC inverter. The converter is controlled by the PWM circuit consists of SG3525 IC. The 65 kHz switching signal control the parallel connected Power MOSFETS. The ferrite transformer output is applied to the full-wave bridge and after filtering process, the high voltage DC ($\approx$ 340V dc) is obtained. The DC ~ AC inverter consists of four power MOSFETS, which controlled by the oscillator and switching control circuits. The 230VAC, 50 Hz modified sine wave output is then provided from the output of the inverter [1]-[11].

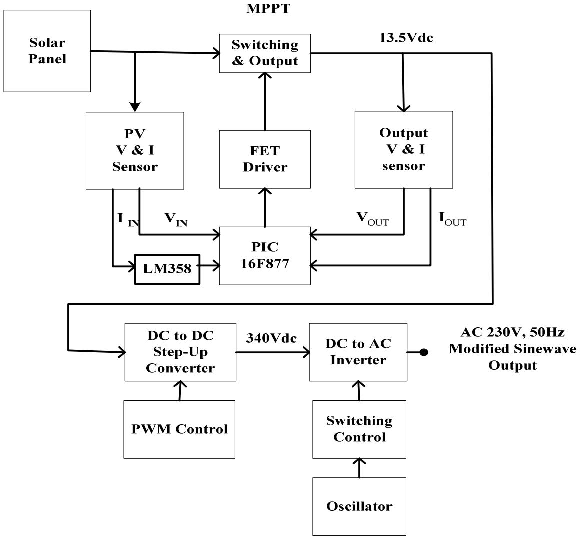

Fig. 1 Block diagram of microinverter system

II. DESIGN CONSIDERATION OF DC-DC CONVERTER

The block diagram of the DC to DC step-up converter is shown below.

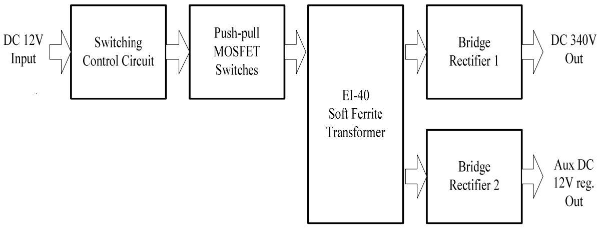

Fig. 2 Block diagram of DC-DC step-up converter

A. *Forward Converter*

To transfer the energy directly between input and output, the simple ferrite transformer is used in the forward converter. Only small size transformer is required for the reason of high operating frequency.

The push-pull type of forward converter is used, and the simplified circuit is shown in Figure 3. The drain terminals of two MOSFET switching transistors Q_4 and Q_5 are connected to individual end of a centre-tapped primary winding of the transformer. The positive line of the input voltage is connected to the centre tap. Q_4 and Q_5 are turned on alternately by the switching signals.

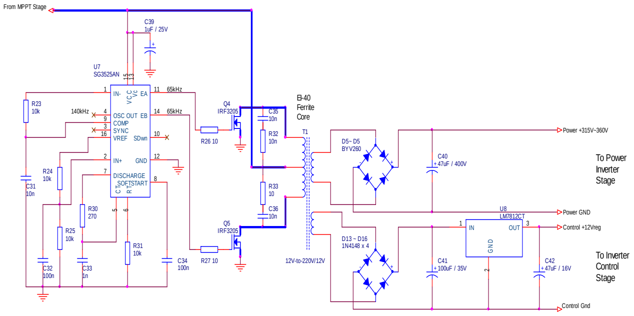

Fig. 3 Forward converter type step-up converter

The sources of MOSFETs are connected to the negative line of the input voltage. The input voltage is applied alternately to the primary windings and so the current flows through into N_{P1} and N_{P2} also interchange in specific frequency.

This frequency relatively high rate, often tens of kHz, so the switching of Q_4 and Q_5 is to change the DC input voltage into a high frequency AC square wave. Then the maximum (peak) voltage of secondary winding is equal to

$$V_{ac}\,(\max) = V_{IN} \times (N_{S1}/N_{P1}) \qquad (1)$$

where N_{S1} and N_{P1} (N_{P2}) are the number of turns on each winding.

The bridge rectifier which consists of fast-recovery diodes D_1~D_4 is connected directly on the secondary winding, so the converted high DC voltage is filtered by C_1. The maximum output DC voltage is approximately equal to

$$V_{out} = V_{in} \times (N_{S1}/N_{P1}) \qquad (2)$$

C_{35}-R_{32} and C_{36}-R_{33} are snubber circuit for the MOSFET.

B. *Switching Control Circuit (SG3525 IC)*

The oscillator frequency is determine by

$$f = 1 / C_T\,(0.7R_T + 0.3R_D) \qquad (3)$$

where R_D is R_{30}, C_T is C33 and R_T is R_{31}. To have the oscillation frequency of 140 kHz, $R_{30} = 270\ \Omega$, $R_{31} = 10\ k\Omega$ and $C_{33} = 1$ nF are chosen. So, in actual, the oscillation frequency is 141.22 kHz.

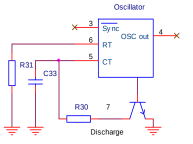

Fig. 4 Oscillator in SG3525 IC

The pulse-width of the output signal is determined by R_{23}~$_{25}$ and C_{33} which connected to the error amplifier stage of the PWM section.

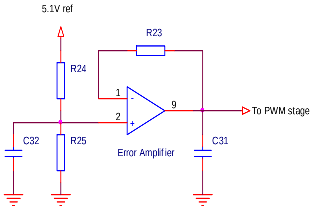

Fig. 5 Error amplifier

SG3525AN has a soft-start function. Capacitor C_{34} is the soft-start condenser. By using the 50uA constant current source present on pin 8, the rise in soft-start capacitor voltage will be linear;

$$-\,i = C\,dv/dt. \qquad (4)$$

When supplying DC voltage from the MPPT stage, step-up DC output will raise linearly from 0 to maximum value. 100nF is chosen for this effect.

The complete switching control circuit is shown below.

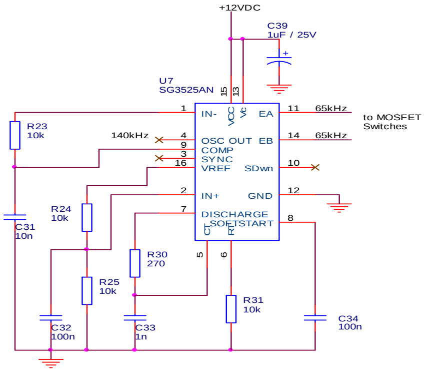

Fig. 6 Switching control circuit

C. *MOSFET Switches*

Low voltage, high current MOSFET is used as the switching device for the DC-DC converter. The control outputs and MOSFET gates are connected via resistance R_{26} & R_{27} of 10Ω.

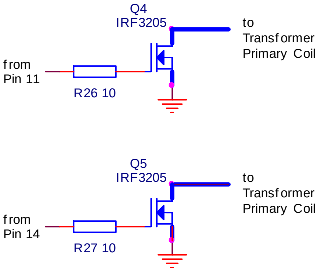

Fig. 7 IRF3205 power MOSFETs

The IRF3205 power MOSFETs has V_{DSS} of 55 V, $R_{DS(on)}$ of 8.0 mΩ and continuous drain current I_D of 110A. Only small size heat-sink is needed for small heat dissipation at high current flow conditions[12].

III. SOFT-MAGNET FERRITE TRANSFORMER DESIGN

For the frequency of 65 kHz and power output of about 275 VA, the MnZn power ferrite core EI-40 is chosen for step-up transformer [13].

To determine the core size

$$K_{gfe} \geq \frac{\rho\lambda_1^2 I_{tot}^2 K_{fe}^{(2/\beta)}}{4K_u (P_{tot})^{((\beta+2)/\beta)}} 10^8 \tag{5}$$

It may be possible to reduce the core size by choosing a core material that has lower loss, i.e., lower K_{fe}.

To evaluate the peak AC flux density,

$$B_{max} = \left[10^8 \frac{\rho\lambda_1^2 I_{tot}^2}{2K_u} \frac{(MLT)}{W_A A_c^3 l_m} \frac{1}{\beta K_{fe}}\right]^{\left(\frac{1}{\beta+2}\right)} \tag{6}$$

At this point, one should check whether the saturation flux density is exceeded. If the core operates with a flux dc bias B_{dc}, then $B_{max} + B_{dc}$ should be less than the saturation flux density.

To evaluate primary turns,

$$n_1 = \frac{\lambda_1}{2 B_{max} A_c} 10^4 \tag{7}$$

and choose the secondary turns according to the desire turns ratio

$$n_2 = n_1 \left(\frac{n_2}{n_1} \right) \tag{8}$$

$$n_3 = n_1 \left(\frac{n_3}{n_1} \right) \tag{9}$$

And finally, the wire sizes are to be chosen as amperage of the standard wire gauge.

The EI-40 soft ferrite core has A_L = 4860 nH/N^2, Ae = 148 mm^2, l_e = 77 mm, V_e = 11534 mm^2 and P_c = 348 W (max.) Required values for windings are V_1 = 12V/20A, V_2 = 340V/ 0.6A and V_3 = 18V/ 0.5A. Switching Frequency is 65 kHz (λ = 15.38µsec).

The turn ratio of primary and secondary are

$n_1/n_2 = 12/340 = 1:28.33$
$n_1/n_3 = 12/18 = 1:1.5$

The primary volt-sec can be calculated as

$$\lambda_1 = V_1(t) \text{ x } D \text{ x } T_{on} \tag{10}$$
$$\lambda_1 = 30 \text{ volt-}\mu\text{sec}$$

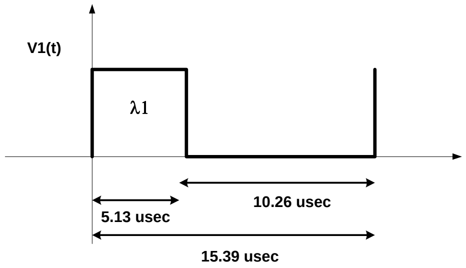

Fig. 8 Control output waveform

TABLE 1

DATA OF TRANSFORMER

Wire effective resistivity	ρ	1.724 x 10^{-6}(Ω-cm)
Total rms winding current, ref to pri	I_{tot}	20 (A)
Desired turns ratio	n_2/n_1 n_3/n_1	1:28.33:1.5
Applied pri volt-sec	λ_1	30 (V-sec)
Allowed total power dissipation	P_{tot}	235 (W)
Winding fill factor	K_u	0.25(assume)
Core loss exponent	β	2.6
Core loss coefficient	K_{fe}	5.5 (W/cm^{3}T$^\beta$)
Core cross-sectional area	A_c	1.56 (cm^2)
Core window area	W_A	3.486 (cm^2)
Mean length per turn	MLT	8.12 (cm)
Magnetic path length	l_e	7.7 (cm)
Wire areas	A_{w1}	(cm^2)
Peak ac flux density	B_{max}	(T)

Therefore, calculate the maximum flux density from the equation (6)

B_{max} = 0.07556 Tesla

By using equation (7), n_1 = 1.273 turns, n_2 = 36.01 turns and n_3 = 1.91 turns

In pratice, n_1 =1.5 turns, n_2 = 43 turns and n_3 = 3 turns

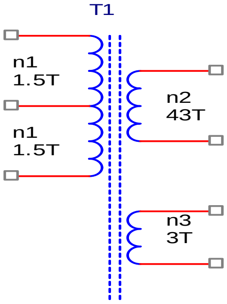

Fig. 9 Step-up transformer

For primary winding, the 3 strand of SWG20 enamelled copper wire is used. SWG24 EC wire is chosen for secondary high voltage winding and SWG22 EC wire is chosen for auxiliary secondary winding.

The secondary winding n_2 is wound first on the former and insulated by HT tape. Then the two primary windings n_1 are wound over secondary winding. The uppermost winding is the n_3.

Fig. 10 Complete MnZn power ferrite core EI-40

A. The Rectifier Sections

To rectify the high-frequency AC voltage, the full-wave bridge rectifier which consists of four fast recovery diodes (BYV 260) is used and filtered by 47µF, 470V electrolytic capacitor. This high-voltage DC is used for inverter stage.

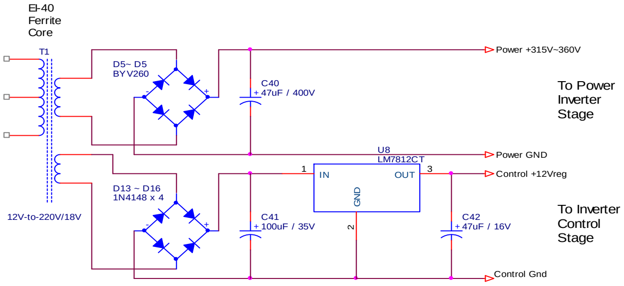

Fig. 11 The rectifier circuit

Another secondary winding is rectified by 1N4148 switching diodes which formed as also full-wave bridge rectifier and filtered by 100µF, 35V electrolytic capacitor. Then, DC voltage is regulated to +12VDC by 3-terminal regulator IC LM 7812CT and filtered by 47µF, 16V electrolytic capacitor. This voltage is supply to the controlled ICs in inverter stage.

IV. EXPERIMENTAL RESULTS OF CONSTRUCTED DC-DC STEP-UP CONVERTER

The complete prototype DC-to-DC converter is constructed on a single IC strip-board as followed.

Fig. 12 Completely constructed PCB of DC-DC step-up converter

In practical, the outputs frequencies of the SG3525AN are slightly lower than the calculated values. Instead of 65 kHz, two outputs have 58 kHz according to the quality of the discrete components from the local markets.

These wave forms are as followed.

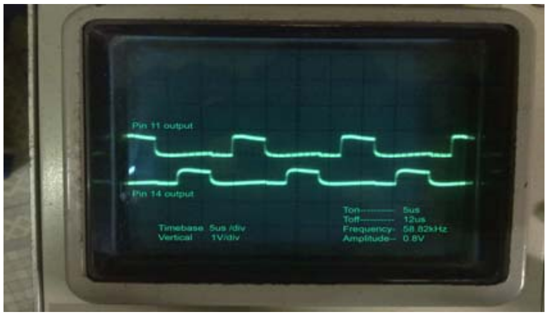

Fig. 13 Control IC output waveforms

The wavelength is about 17 µsec and T_{on} is about 5 µsec and T_{off} is about 12µsec.

(The calculated value of wavelength is 15.39 µsec and T_{on} is 5.13 µsec and T_{off} is about 10.26 µsec.)

DC input voltage = 12VDC (13.7V)
DC high voltage output = 340V (360V)
DC auxiliary voltage = 11.86 V regulated. (11.86 V)

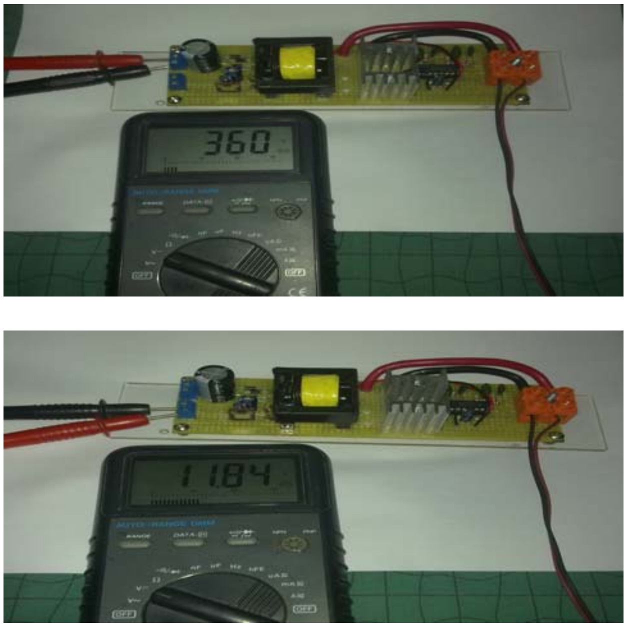

Fig. 14 Measured results of DC-DC step-up converter

V. CONCLUSIONS

In this paper the operation, design and considerations of a push-pull based DC-DC forward converter for 200W microinverter.The DC-DC forward converter is the most suitable topology in this system. The galvanic separated effect of the input and output is the main advantage of this topology and utilisation of very low R_{DON} MOSFET give low losses. This is an important advantage since the largest losses in the converter appear in the MOSFET switches. Thereby reducing all of the losses to the lowest possible level, considerably improves the converter efficiency. Switching frequency of the converter was chosen 65 kHz, allowing creating a compact and noiseless converter with reasonable switching losses.

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