

Design and control of current source flyback micro inverter for single grid connected photovoltaic systems

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Abstract—The proposed design of current source micro inverter system is used to connect PV panel to the grid with achieving maximum Power Point Tracking (MPPT) control. The main advantages of the proposed micro inverter are: low cost, high efficiency, high power density and high power factory regulation. The proposed Flyback micro inverter operates in discontinuous conduction mode (DCM) where a constant switching frequency control is applied.

The design and the control are validated by personal computer simulation program (PSIM) and experimental laboratory prototype is accomplished

Keywords— Single-Stage, Grid-Connected, Micro inverter, Flyback, DCM, MPPT, current source

I. INTRODUCTION

Solar energy presents a promising source for producing clean electricity generation.

In the world, there are two potential markets for electric power generation from photovoltaic (PV) systems:

- Large-scale (up to several megawatts) power plants sized used in desert regions with high insolation, PV standalone or grid-connected systems for professional use
- Small-scale residential applications, where the PV power production usually varies between 0.1 and 5 kW.

The use of several decentralized grid connected PV systems is quite more appropriate as they can also be easily installed on buildings.

Technology on decentralized grid-connected PV systems is so-called "ac-PV module". Ac-PV module is the combination of a single PV module and a single phase power electronic inverter. Power process unit of Ac-PV module is usually a single phase controllable power converter, power range from 50–400 W.

Ac-PV inverter is mounted either on the rear side of the module or on the support structure and is directly connected to the PV module. The concept of ac-PV module supports optimal adjustment between the PV module and the inverter, which may lead to an overall better performance

II. PROPOSED MICRO INVERTER

Fig.1 presents the proposed Flyback micro inverter performs energy from DC side to the AC grid site. Micro inverter includes different parts:

- High frequency transformer with three windings: one primary and two secondary
- A primary controlled switch S1 is modulated in high frequency, duty cycle should be made to vary throughout the AC voltage line cycle.
- The two secondary controlled switches placed in each secondary winding SV2 and SV3 are modulated with grid frequency. Each of them is able to transfer energy to the AC side during a utility grid half cycle and they ensure an AC output wave form synchronized with the grid.
- LC filter is used to filter the current produced by the rest of the converter; so that the appropriate final output current is produced and fed to the grid.

The control bloc of Flyback micro inverter includes:

- Phase locked loop PLL bloc that generates signal, controls each controlled switch SV1,SV2 and SV3
- A maximum power point extractor MPPT bloc that calculates the duty cycle Dmax in order to extract the maximum power from photovoltaic panel

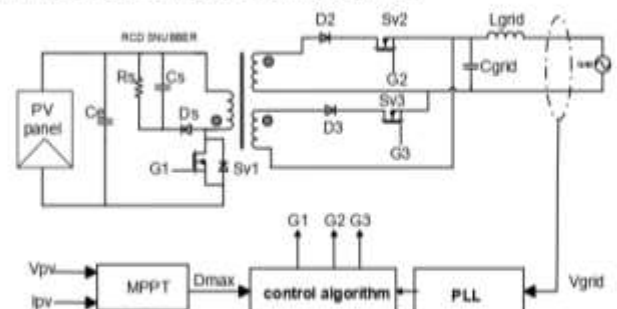


Fig. 1 Proposed Flyback micro inverter

The switching sequence of each semiconductor can be observed in Fig.2.

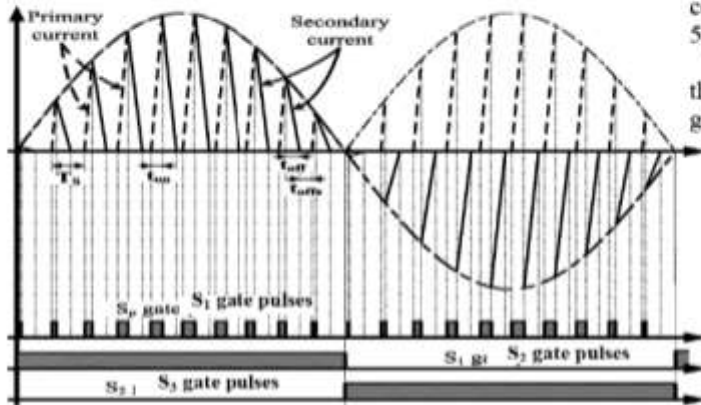


Fig.2 switching sequence of SV1, SV2 and SV3

III. OPERATION MODE OF FLYBACK MICRO INVERTER IN DCM MODE

When the primary switch SV1 is on; the primary current I1 in the primary winding of transformer increases, the energy coming from the solar PV panel is stored in the magnetizing inductance Lm of the HF transformer.

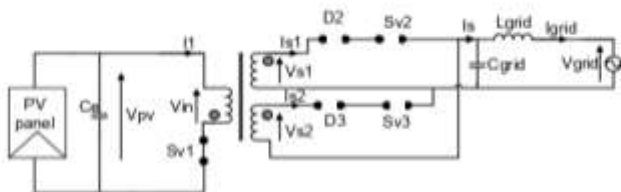


Fig.4. Micro inverter when primary switch Sv1 is on

The voltage at the primary winding of transformer is:

$$V_{in} = NVg(t) = L_m \frac{dI_1(t)}{dt} \quad (1)$$

When N is the turns ratio ($N=N_p/N_s$), L_m magnetizing inductance.

The pic value of primary current I_{1max} can be expressed

$$I_{1max} = \frac{V_{in,dmax}}{L_m f_s} \quad (2)$$

The ton_max can be expressed as:

$$ton_{max} = dmax \cdot T_s = \frac{dmax}{f_s} \quad (3)$$

When $dmax$ is the maximum duty cycle and f_s the switching frequency of primary switch SV1, The AC grid voltage can be expressed as:

$$Vg(t) = Vgmax \cdot \sin(\omega_g \cdot t) \quad (4)$$

When SV1 is off, the stored energy in the HF transformer will transfer to the grid through the output rectifier D2 and the controlled switch SV2 if the grid voltage V_{grid} is positive (Fig 5).

The stored energy in the HF will transfer to the grid, through the output rectifier D3 and control switch SV3 when grid voltage V_{grid} is negative (Fig 6).

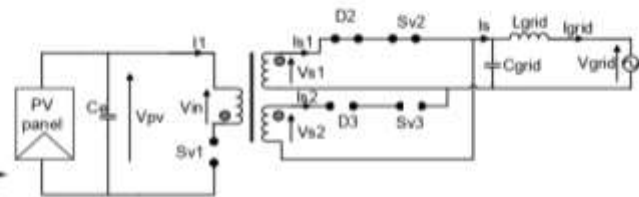


Fig.5. Micro inverter when primary switch Sv1 is off

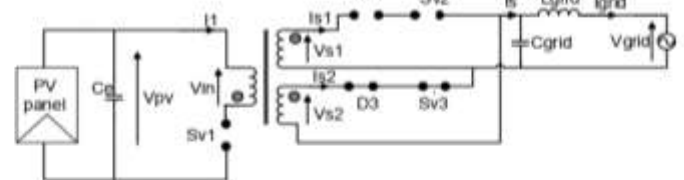


Fig.6 Micro inverter when primary switch Sv1 is off

The proposed flyback micro inverter operates in discontinuous conduction mode (DCM) due to its simplicity of control

To operate in DCM, the maximum duty cycle can be expressed:

$$dmax \leq \frac{1}{\frac{V_{in}}{NVgmax} + 1} \quad (5)$$

The magnetique inductance L_m can be expressed

$$L_m = \frac{1}{2} \left(\frac{V_{in}}{Vgmax} \right)^2 \frac{dmax^2 Vgmax^2}{f_s \cdot L_m} \quad (6)$$

IV. SIMULATION RESULTS

The proposed converter was simulated using PSIM software. The converter was implemented with the following specifications:

Table 1
Inverter parameters

Parameters	value
Rated output power P_s	150W
Switching frequency f_s	60Khz
Magnetizing inductance L_m	6.65μH
PV input voltage V_{pv}	30V
Grid frequency f_{grid}	50Hz
Input capacitor C_e	10μf

Turn ratio of transformer N	0.11
Output filter capacitor	300nf
Output filter inductance	2mH

Fig.7 shows the voltage value across SV1 switch. The voltage is zero for the conduction phase of the transistor. The overvoltage reaches 120V caused by leakage inductance of the transformer

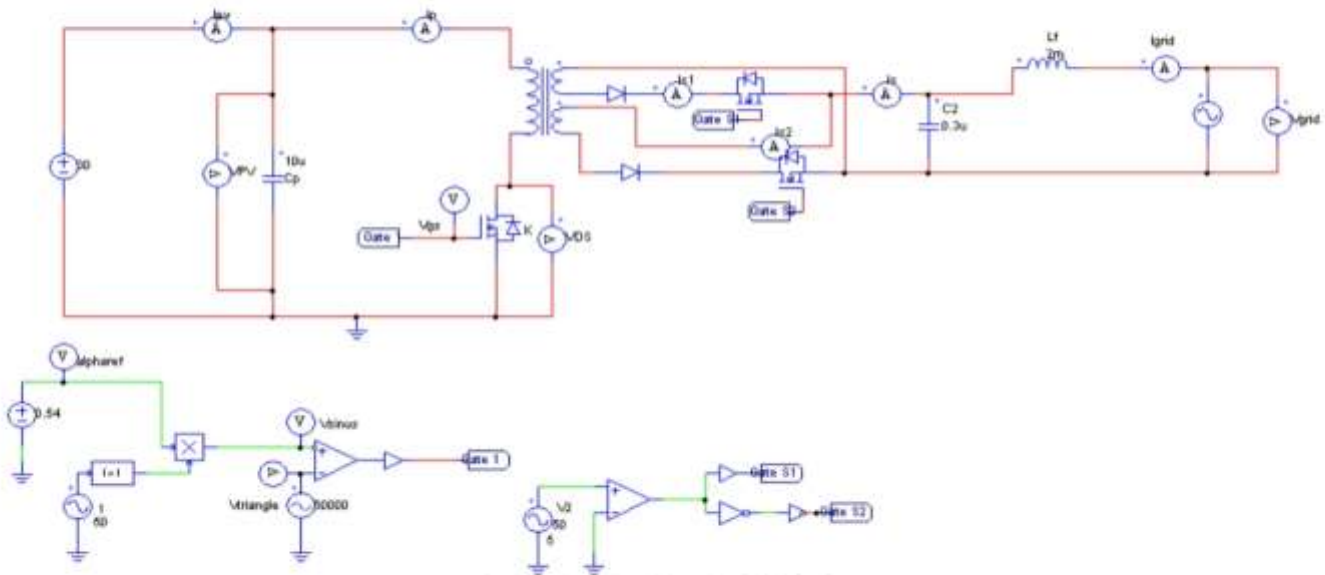


Fig.7 inverter simulating using PSpice software

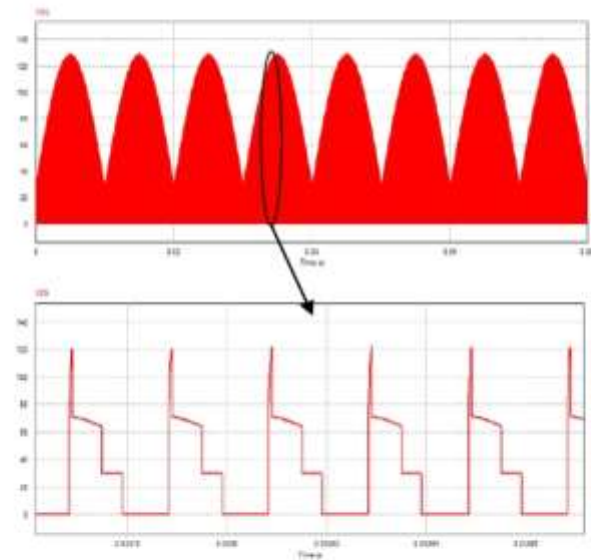


Fig.8 voltage value across SV1 switch

Fig.9 shows the primary transformer current I_p . The current reaches 40A, when the primary switch SV1 is on

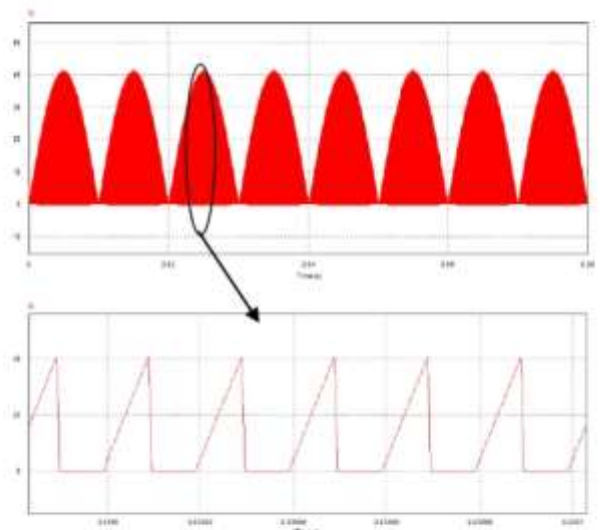


Fig.9 primary transformer current I_p

Fig.9 shows the secondary currents I_{S1} and I_{S2} before filtering for the case of 150W constant active power transfer. Fig.10 and Fig.11 show grid injected current and grid voltage after CL filter.

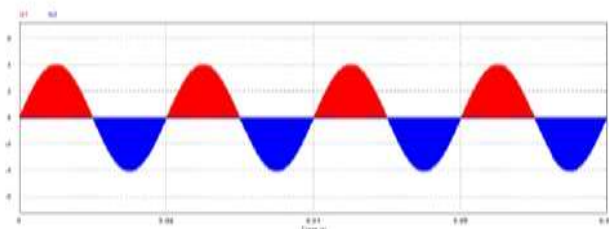


Fig.9 secondary current IS1 and IS2

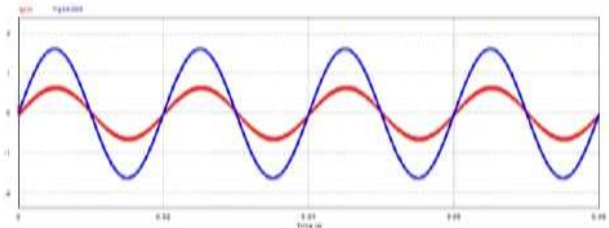


Fig.10 output voltage and current

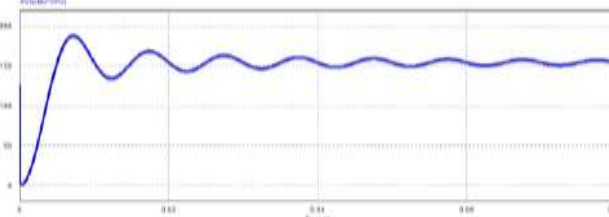


Fig.11 injected power

V. EXPERIMENTAL RESULTS

Laboratory experimental prototype was built (Fig. 12), with the component values selected by the algorithm. The flyback inverter is controlled by the STM32F407 microcontroller.



Fig.12 experimental prototype

Fig. 13 shows the inverter output current and voltage injected in the load with unit power factor.

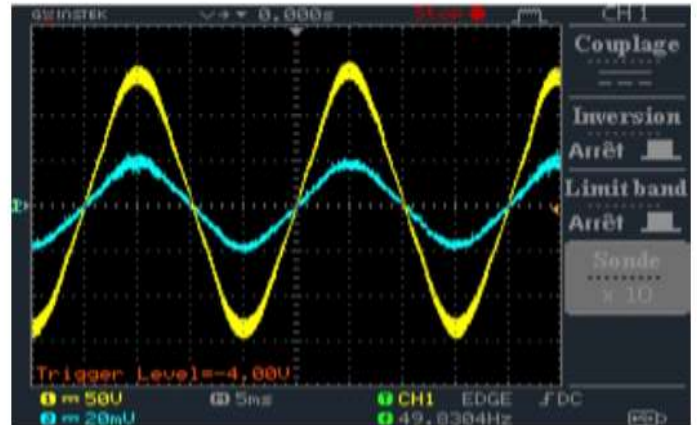


Fig.13 load voltage (ch1,50V/div) and current (ch2,200mA/div)

VI. CONCLUSION

The advantages of the flyback current source inverter qualify it to be used as a single stage converter in photovoltaic modules. The proposed micro inverter operates in discontinuous conduction mode (DCM) where a constant switching frequency control is applied. Flyback micro inverter can also operate in BCM and CCM but control mode is complicate and must operate in a closed loop control.

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