IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331,
PP 50-58
www.iosrjournals.org

Resonant Inverter

Ms.Kavitha Paul[1], Mrs.Gomathy S[2]
[1](*EEE Department Adi Shankara Institute of Engineering and Technology, India)*
[2](*EEE Department Adi Shankara Institute of Engineering and Technology, India)*

Abstract: *Paper proposes a grid-connected quasi resonant flyback micro inverter for pv applications. A new micro inverter topology with paralleling technique with hysteresis control is suggested for better harmonic elimination , reduction in power losses and thermal stresses in the converter and to achieve low profile design for low power applications.*

I. Introduction

Photo voltaic system based on micro inverter architectures are gaining popularity in recent years as it has got less prone to shading effects and array malfunctioning. Centralized and string inverter structures are adopted in traditional solar energy systems [1]. Central inverter architectures are good choice for high power applications where few inverters are used with many pv modules. Fig.1(a) shows the architecture of central inverter. String inverter is used for just one string of modules and these strings are connected together to form large systems. Fig. 1(b) shows string inverter structure. However these structures has got lot of disadvantages such as high DC bus voltage, poor anti shadow ability and less over all efficiency. Development of micro inverter structure make it possible to resolve these issues. In micro inverter architecture , each panel has its on inverter for power conversion. If one panel is shaded, efficiency of that particular panel is affected, however the rest of the panels are unaffected. Micro inverter will operate with small individual output voltages rather than hazardous high DC bus voltage. Fig. 1(c) shows micro inverter structure.

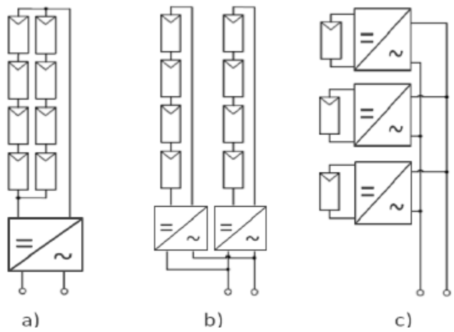


Fig. 1. Different architecture of pv inverters.

Over the entire life span , it is estimated that micro inverter harvest more solar energy than central and string inverters. For this reason, micro inverter is becoming more popular for low power application even though the initial installation cost is high. The main focus on this paper is on flyback micro inverter particularly on micro inverter based on quasi resonant flyback converter topology.

II. Literature Review

In this section several single stage flyback micro inverter topologies were discussed. The basic principle behind each flyback micro inverter are reviewed and their various advantages and disadvantages were analysed.

2.1 Conventional flyback micro inverter:

The conventional flyback micro inverter is shown in Fig. 2. The way in which this converter works as follows. When the primary main switch S1 is on , input DC voltage from solar panel appear across the primary winding of the transformer which in turn energize the magnetizing inductance and magnetizing current shoots up. When the switch S1 is off, the energy stored in the inductor is transferred to output which is grid. Deponding on the polarity of grid voltage , either Do1 and So1 is operated when grid voltage is positive or Do1 and So2 is operated if grid voltage is negative. The duty ratio of the main switch must be operated through out the entire AC cycle, that means several control measures must be implemented for better operation .

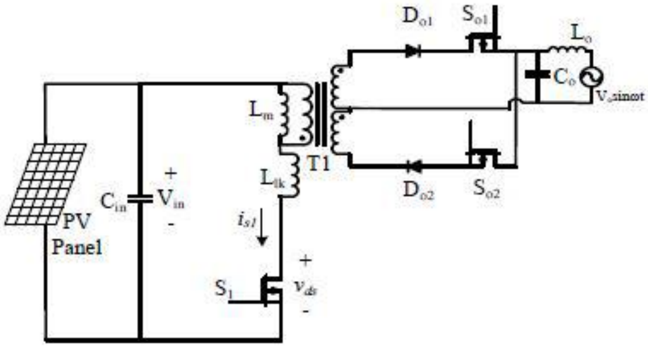


Fig. 2. Conventional flyback micro inverter.

2.2 Active clamp flyback inverter:

In conventional flyback converter ,main primary switch S1 is turned on at zero current(ZCS) , when the inverter is operated at either DCM or BCM as there is no primary current when the switch is turned on, Due to parasitic junction capacitance of the main switch S1, switches are not turned on at zero voltage (ZVS). To operate with zero voltage switching conventional flyback micro inverter is modified with an additional active clamp circuit that allows the primary switch to operate at ZVS [2]-[3]-[8]. An example of active clamp circuit is shown in fig. 3. The inverter operation is same as conventional inverter except that an auxiliary switch Sa is turned on just before main switch S1, which will inject a negative resonant current into the transformer that is used to discharge the parasitic capacitance of main switch. As the parasitic capacitance discharges completely the switch is turned on at ZVS. The disadvantage of this converter is that there may not be sufficient amount of energy that is available to discharge this parasitic junction capacitance completely

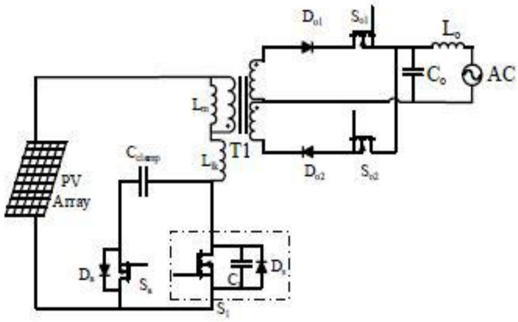


Fig. 3. Active clamp flyback inverter.

2.3 ZVS using grid current:

Modification is done on flyback micro inverter by replacing the secondary diodes with active switches as shown in Fig.4 . This is to make the secondary branches bidirectional so that current can flow in and out of grid. This grid current is used to assist ZVS for main switch S1. Converter working as follows. When S1 is off, transformer demagnetize and magnetizing current drops to zero. As soon as current reaches zero,current will start to flow in reverse direction that is from grid into the converter. This secondary current appear across the converter primary and enables to discharge the parasitic capacitance of main switch S1. Sophisticated control scheme is required to limit the secondary current is the main draw back of this converter.

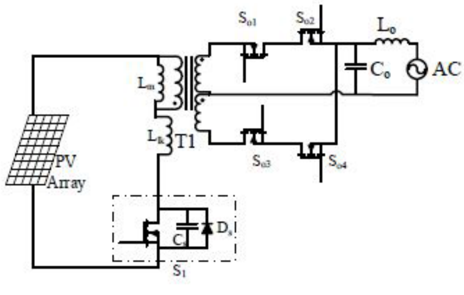


Fig. 4. ZVS using grid current.

2.4 Flyback inverter with switched capacitor turn off snubber:

Turn off losses in the primary switches can be minimized by implementing a turn off snubber as shown in Fig. 5. Primary switch of conventional converter is replaced by a structure that consist of two switches S1 and S2 , two diodes D1 and D2 and a snubber capacitor Cclamp. Two switches are turned on at the same time. When this happens, primary current will flows through both switches S1 , S2 and Cclamp. As the capacitor discharges completely, which may not be the case if primary current is very low, primary current splits, with half current flows through S1 and D2 and other half through D1 and S2. After some time, both S1 and S2 are turned off simultaneously with ZVS.

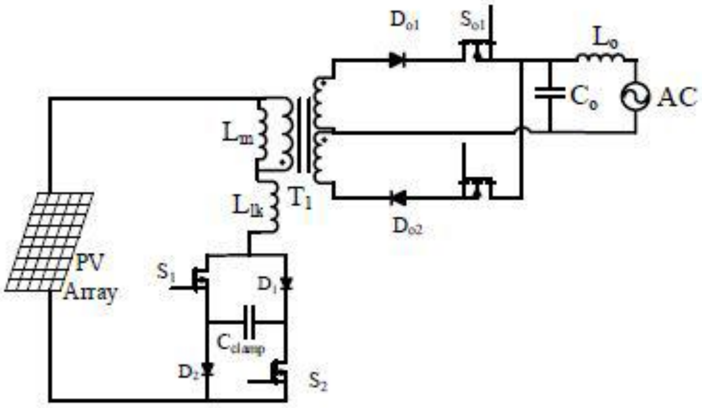


Fig. 5. Flyback inverter with switched capacitor turn off snubber.

III. Proposed Quasi Resonant Fly Back Inverter With Regerative Snubber

The general principle behind ZVS operation of a converter is that, the current must flow through the internal body diode before the switch is turned on. Doing so it ensures that there is no energy stored in its output capacitance. Power loss associated with the switched output capacitance can be expressed as :

$$p_{loss}\,on = \frac{1}{2}{V_{ds}}^2 fs \text{...}(1)$$

where fs is the switching frequency and Vds is the voltage across drain and source of MOSFET. A basic quasi resonant DC DC flyback converter is shown in Fig. 6.

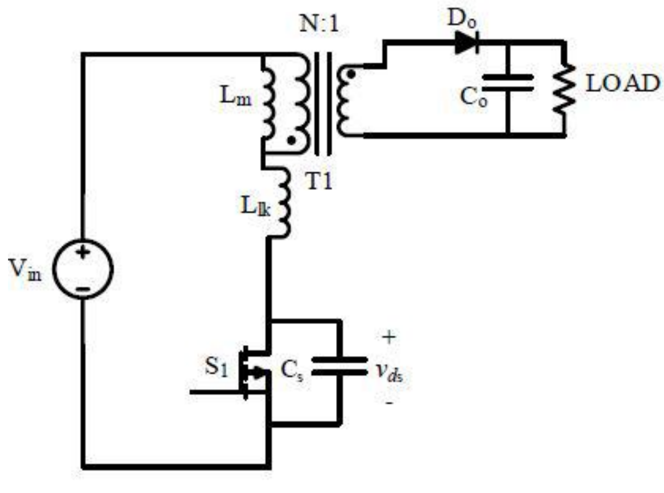


Fig. 6. Quasi resonant DC DC flyback converter

Converter is operated with Lm in DCM, the secondary current ceases conduction before the primary switch turned on. The primary current(i_{si})starts resonates as the secondary diode Do ceases conduction at t1 = T1andT5 as shown in Fig. 7.

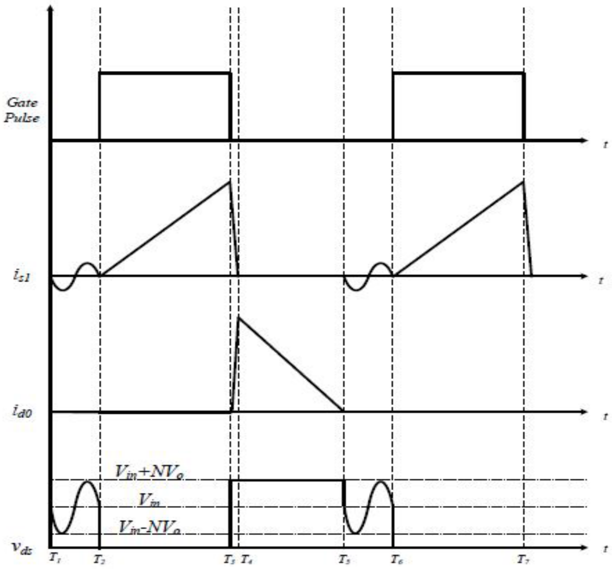


Fig. 8. Typical operating waveform of flyback converter

This resonance is caused by the interaction of output capacitance of main switch and equivalent magnetizing inductance Lm. Thus Cs discharges and recharges as the voltage swings between peak voltage (Vin+NVo) and valley voltage (Vin-NVo). In order to reduce the switching loss converter is always switched at valley voltage[4]. Switching at valley voltage depends on the time period of resonating cycle(T_R) caused by the interaction of Lm and Cs. The resonating cycle occur just after the transformer demagnetization. Secondary current flows to zero during interval T1-T2 and T5-T6.

$$T_R = 2\pi\sqrt{(L_m + L_{lk})}C_s \text{ ....(2)}$$

The voltage across switch reaches minimum value at half of resonating cycle $T_R/2$. A Quasi resonant flyback micro inverter with passive regenerative snubber is proposed in this paper. The main feature of this converter is that efficiency gain can be achieved using a very simple passive snubber circuit[5] as shown in Fig. 9. Converter primary side is like DC to DC flyback converter with with S1 being the main switch. A passive snubber consisting of diode D1 and D2 , capacitor Cclamp and transformer winding Tr is attached to the primary side.

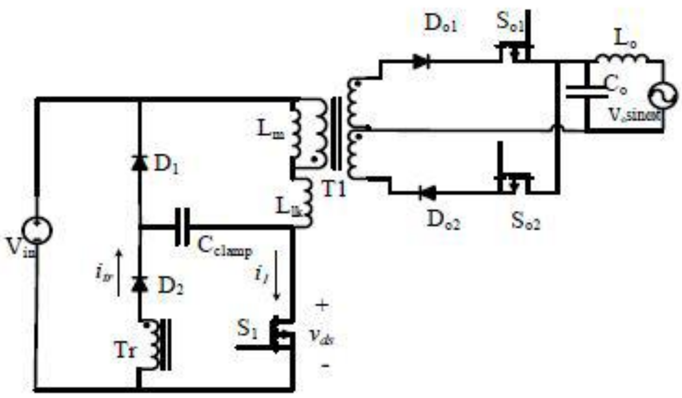


Fig. 9. Quasi resonant micro inverter

Flyback micro inverter goes several modes of operation during its switching cycle. the modes of operation of converter is as follows which is shown in fig. 10.

3.1 Mode 1 (To-T1):

Primary switch S1 is turned on at t = T0. Source voltage is impressed across the transformer primary winding and transformer magnetizing inductance starts to energize. As the switch S1 is on , diode D2 is also forward biased. Therefore the charged capacitance Cclamp discharges through S1 and auxiliary winding Tr. This mode end as the diode D2 is reverse biased.

3.2 Mode 2(T1-T2):

Capacitor Cclamp has been discharged to such an extent that at t = T2, the voltage across Cclamp will make the diode D2 in reverse biased. Transformer continuous to be magnetized.

3.3 Mode 3(T2-T3):

The main switch S1 is turned off at t = T2. No current will flows through S1, but it flows through two paths, one is through the output capacitance of S1, Cs and other through Cclamp and diode D1. By the end of this mode voltage across Cclamp reaches its maximum value.

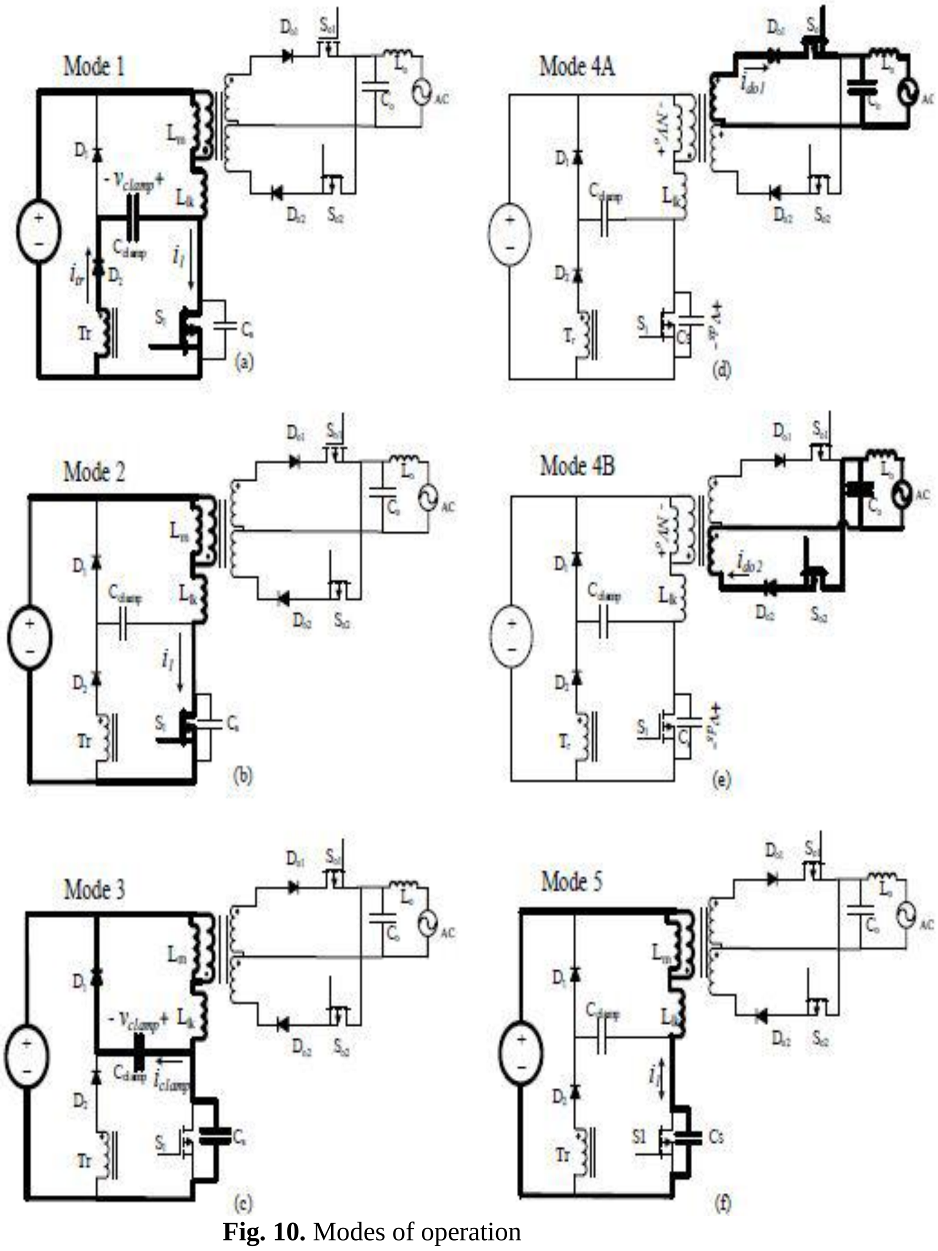


Fig. 10. Modes of operation

3.4 Mode 4(T3-T4):
One of the secondary begins to conduct and transformer demagnetized. The diode that conducts depends on the polarity of the output grid voltage. If the grid voltage is positive , S01 is on and current flows through D01 and if it is negative S02 is on and current flows through D02. At T4 secondary current goes to zero.

3.5 Mode 5(T4-T5):
As secondary current reduce to zero, transformer primary and secondary windings become decoupled so that primary voltage is no longer equal to reflectedoutput voltage and this allows D2 to be in forward biased. The conduction of D2 depends on the resonance between equivalent inductance and Cclamp capacitance. The duration of resonant cycle is half the duration of resonant period as diode D2 is is then reverse biased. ZVS is achieved at the end of resonant period at time T5. Resonant circuit for mode 5 is shown in Fig. 11.

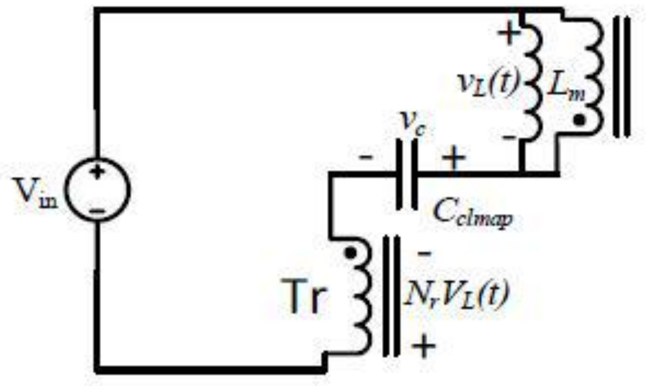


Fig. 11. Resonant circuit for mode 5 operation.

Resonant time period Tqr is given by

$$T_{qr} = 2\pi\sqrt{C_{clamp}(1 - N_r)L_m} \quad ....(3)$$

Total time period of a switching cycle can be written as

$$T_s(t) = T_{on}(t) + T_{Do}(t) + T_{qr}/2 \quad ....(4)$$

where Ton is the on time required for ZVS turn on and TDo is the secondary diode conduction time.

IV. Simulation Result
Converter is designed according to the following specifications . Input voltage is 40V, grid voltage is 230V AC, grid frequency is 50Hz , switching frequency is 100kHz and maximum output power is 100W.

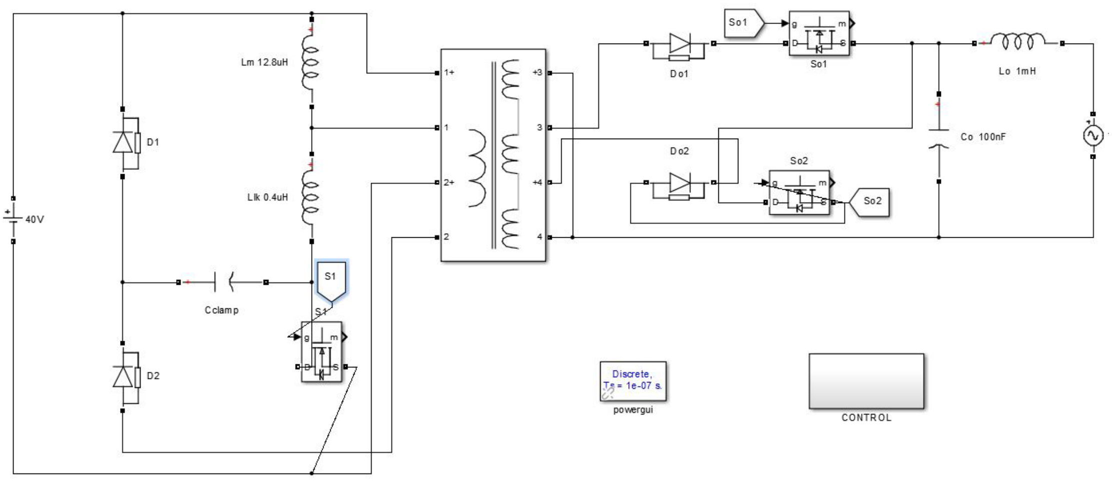
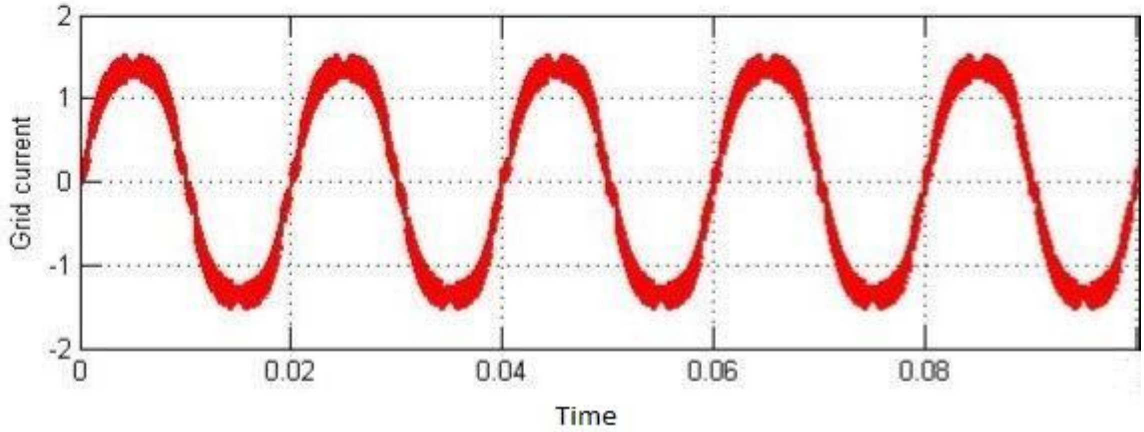


Fig. 12. Simulation for quasi flyback micro inverter




```
Sampling time     = 1e-07 s
Samples per cycle = 200000
DC component      = 9.717e-05
Fundamental       = 1.53 peak (1.082 rms)
THD               = 9.30%

    0 Hz  (DC):          0.01%    270.0°
 12.5 Hz                 0.01%    268.7°
   25 Hz                 0.01%    267.4°
 37.5 Hz                 0.01%    266.2°
   50 Hz  (Fnd):       100.00%     -1.4°
 62.5 Hz                 0.01%    263.9°
   75 Hz                 0.01%    262.9°
 87.5 Hz                 0.01%    262.0°
  100 Hz  (h2):          0.01%    261.2°
112.5 Hz                 0.01%    260.6°
  125 Hz                 0.01%    260.0°
137.5 Hz                 0.01%    259.5°
  150 Hz  (h3):          9.12%     -0.1°
162.5 Hz                 0.01%    258.6°
  175 Hz                 0.01%    258.3°
187.5 Hz                 0.01%    257.9°
  200 Hz  (h4):          0.01%    257.5°
```

Fig. 13. Grid current and harmonic analysis

Harmonic distortion is observed to be 9.30%. According to IEC[9] standard maximum current THD should be less than 5%. so in order to reduce the harmonic content in grid current ,direct paralleling technique with hysteresis control is applied to the proposed quasi resonant micro inverter.

V. Direct Paralleling

Paralleling of converter power module are well known technique , to achieve desired output waveforms as shown in fig. 14. Itis a general method to eliminate power losses and thermal stresses in power modules without increasing the number of power stages, the transformer magnetic can be distributed by using direct paralleling technique.

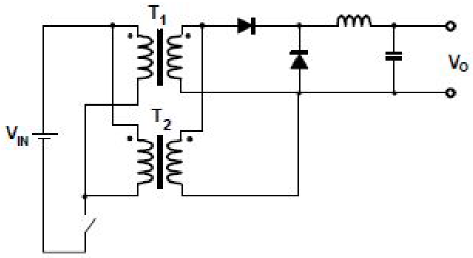


Fig. 14. Direct paralleling of converters.

In hysteresis current control, PWM signals are generated by using hysteresis comparator which will compare command current i_c^* and actual current ic[6] as shown in Fig. 15. It is a real time control, fast response and simple approach to reduce the current distortion.

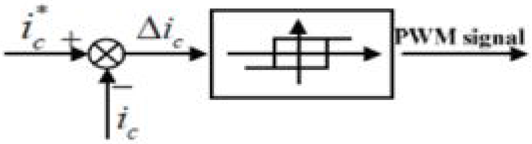


Fig. 15. Hysteresis control.

VI. Simulation Of Proposed Systems And Its THD Result

Simulation in Fig. 16 shows a quasi resonant flyback inverter with direct paralleling technique and hysteresis controller is adopted so that total harmonic distortion is obtained to be 2.75%.

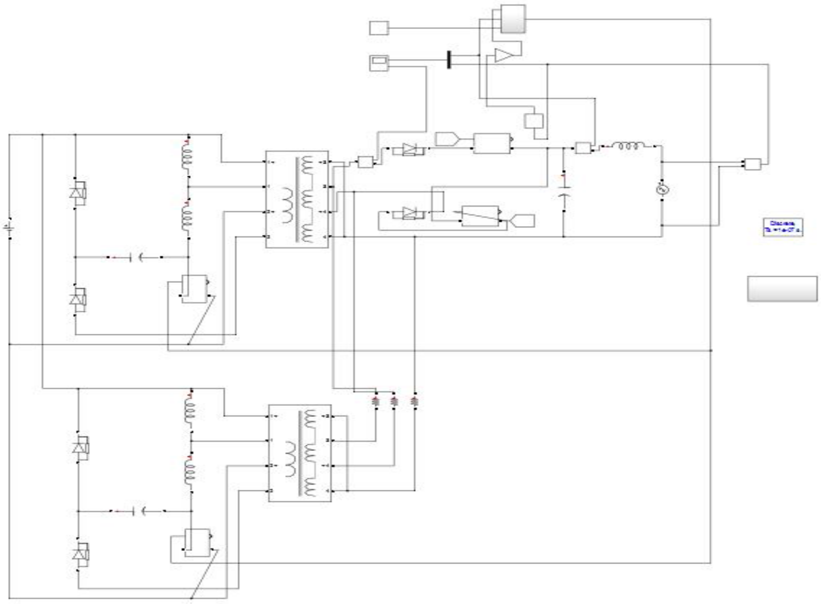
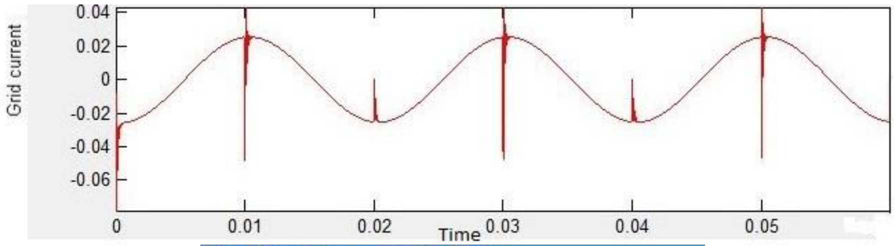


Fig. 16 simulation of proposed quasi resonant micro inverter




```
Sampling time      = 1e-07 s
Samples per cycle  = 200000
DC component       = 0.0001364
Fundamental        = 0.02514 peak (0.01777 rms)
THD                = 2.75%

    0 Hz   (DC):      0.54%   270.0°
 12.5 Hz              0.70%   268.2°
   25 Hz              0.70%   267.1°
 37.5 Hz              0.69%   265.7°
   50 Hz   (Fnd):   100.00%   263.1°
 62.5 Hz              0.68%   264.4°
   75 Hz              0.67%   263.3°
 87.5 Hz              0.67%   262.6°
  100 Hz   (h2):      1.04%   264.4°
112.5 Hz              0.65%   260.2°
  125 Hz              0.65%   259.8°
137.5 Hz              0.64%   259.3°
  150 Hz   (h3):      1.31%    89.4°
162.5 Hz              0.63%   259.7°
  175 Hz              0.62%   259.3°
187.5 Hz              0.62%   259.2°
```

Fig. 17. Grid current and harmonic analysis

VII. Conclusion

A novel technique for improving the efficiency of DC to AC micro inverter was proposed in this paper. This system consist of a simple snubber circuit consisting of few passive elements and converter is operated on quasi resonant principle to achieve ZVS. Harmonic analysis were done by direct paralleling of converter with hysteresis control. It was found that proposed grid connected converter has a THD of 2.37% which is less than 5%. Simulation results were obtained and confirmed the feasibility of proposed micro inverter.

References

[1]. M. Calais, J. Myrzik, T. Spooner and V. G. Agelidis, Inverters for single-phase grid connected photovoltaic systems-an overview,inProc.IEEE PESC,2002, pp. 1995-2000.

[2]. N. Kasa, T. Iida and A.K.S. Bhat,Zero-voltage transition flyback inverter for small scale photovoltaic power system, in Proc.IEEE PESC, 2005,pp. 2098-2103.

[3]. R. C. Variath, M. A. E. Andersen, O. N. Nielsen and A. Hyldgard,A review of module inverter topologies suitable for photovoltaic systems,in Proc.IEEE IPEC,2010, pp. 310-316.

[4]. R.B. Ridley, W.A. Tabisz, F.C.Y. Lee and V Vorperian, Multi-loop control for quasi-resonant converters, in Proc.IEEE Trans. on Power electron.,vol.6, no.1, pp.28-38, Jan., 1991

[5]. A. Abramovitz, T. Cheng and K. Smedley, Analysis and Design of Forward Converter With Energy Regenerative Snubber, in Proc.IEEE Trans. on Power electron,vol.25, no.3, pp.667-676, Mar., 2010

[6]. M. Gao, M. Chen, Q. Mo, Z. Qian and Y. Luo, Research on output current of interleaved-flyback in boundary conduction mode for photovoltaic AC module application, in Proc. IEEE Ener. Conv. Cong.& Expo. (ECCE),2011, pp.770-775.

[7]. Z. Zhang, X.F. He and Y.F, Liu, An Optimal Control Method for Photovoltaic Grid-Tied- Interleaved Flyback Microinverters to Achieve High Efficiency in Wide Load Range, in Proc. IEEE Trans. on Power electron,vol.28, no.11, pp.5074-5087, Nov. 2013.

[8]. Q. Mo, M. Chen, Z. Zhang, Y. Zhang and Z. Qian,,Digitally controlled active clamp interleaved flyback converters for improving efficiency in photovoltaic grid-connected micro-inverter, in Proc. IEEE Appl. Power Elec. Conf. (APEC) 2012., pp.555-562.

[9]. S. B. Kjaer, J. K. Pedersen and F. Blaabjerg, A review of single-phase grid-connected inverters for photovoltaic modules, IEEE Trans. on, Ind. Appl., vol. 41, pp. 1292-1306, 2005.