

Passive Soft-Switching Snubber Circuit with energy recovery.

Alexander Isurin (sashai@vanner.com) and Alexander Cook (alecc@vanner.com)

Vanner Inc, Hilliard, Ohio

Abstract-This paper describes a passive snubber circuit with energy recovery to the source. This circuit uses only passive components and can work with a full-leg power conversion topology, i.e., using standard IGBT modules. The circuit provides soft-switching, that is ZVS turn off, reduces slew rate, and increases efficiency around 1% under full load conditions (tested on a DC-AC inverter at 12kW load and 120VAC output). The authors suggest that this passive snubber circuit can work with many types of converters.

I. BACKGROUND

At the present time the majority of power supplies or power converters use switch-mode technology. In this technology, it is very important to ensure that the active devices remain within their SOA. This problem can be generally solved by three ways:

One is soft-switch technology with ZCS and ZVS. This technology is very successful and has many types when it is used for DC-DC converters. But for a DC-AC inverter with a low modulation frequency (up 400 Hz) we don't have a big selection of tools for soft-switch technologies suitable for a full-leg (half bridge) power conversion with standard IGBT modules. Generally an ARCP (Auxiliary resonant commutated pole) is used [1, 2]. This method produces good results, but it requires additional active switches and makes control more complicated which significantly increases cost and reduces reliability. Others [3] offer a reduction in the number of active switches, but finally it is still not simple and cost effective.

The second is an overrated device sufficient to stay within its SOA, but it is clear that this method is unsatisfactory due to the cost and size that it entails.

The third is passive snubber circuits, which control the "load line" of power devices. Simple snubber RCD circuits have significant disadvantages. The first one is power consumption, sometimes as much as 2-3% of the nominal power rating of the converter. A number of snubber designs have solved this problem by adding inductors and transformer for recovery energy to the load [4,5,6] or to the source [7,8,9]. Common disadvantages of these circuits are that they cannot work with standard IGBT modules or they only work for Boost or Buck converters [4,5,6,8]. Energy recovery to the load can also be a problem under light load or idle conditions. This problem can be solved by using more complicated control (e.g., variable

commutation frequency with PWM) that of course impacts the cost.

II. TECHNICAL DESCRIPTION

In this paper, we are going to describe a relatively simple snubber without the disadvantages which are described above. It uses only passive components, and it has energy recovery to the source. Generally a minimum of 70-80% of the energy which is used for the controlling the power switch "load line" would be returned to the source. The proposed snubber circuit is suitable for use in full leg power conversion.

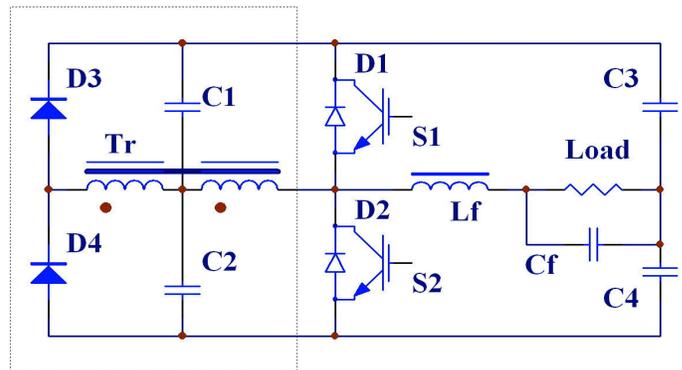


Fig.1 The proposed snubber circuit

Fig.1 shows an example where the proposed snubber circuit is connected to typical half-bridge DC-AC converter where S1,S2,D1 and D2 belong to the half bridge, and where C1,C2,D3,D4 and Tr belong to the snubber. To describe and analyze the proposed circuit we will make the assumption that all semiconductors are ideal and use the schematic of a buck converter for simplicity. Fig.2 shows the snubber circuit including the transformer parasitics, specifically with leakage inductance, magnetizing inductance, and winding resistances. Fig.2 to Fig.8 show one capacitor C_{eq} instead of C1 and C2. Two capacitors are required to provide more symmetrical behavior of snubber in practice or, in other words, to compensate for other circuit parasitics.

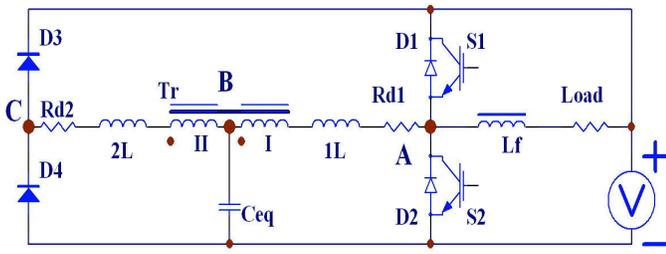


Fig.2 The snubber circuit including the transformer parasitics

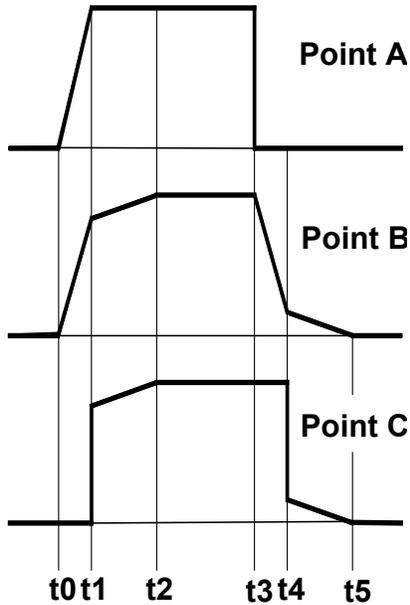


Fig.3 Theoretical waveforms of the snubber circuit, S2 is the active power switch

Fig.3 shows theoretical waveforms of the snubber circuit when S2 is the active power switch. Fig.4-8 show equivalent circuits of each operational mode. Let us start with Fig.4 which is for the time segment t0-t1. At t0 switch S2 turns off interrupting the current from the source to the load via S2 and Lf, starting the fly back process. The current from Lf begins to charge capacitor Ceq via the primary winding of the transformer Tr. Between time t0 and t1 the secondary winding of the transformer is shunting the primary winding via D4, the secondary winding, and capacitor Ceq. In this case the capacitor Ceq will be charged via the leakage inductance of the transformer and windings resistances, but the value of leakage inductance is so small that we can assume that the capacitor will charge linearly to time t1. The capacitor Ceq is charged by current $I = I_1(1 + N)$

where: I_1 is the current in the primary winding of transformer which in this case flows from Lf, N is the turns ratio of the transformer, primary to secondary.

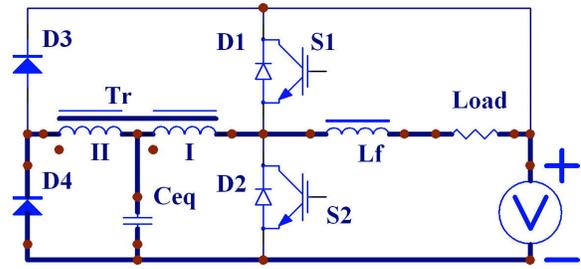


Fig.4 Time t0-t1

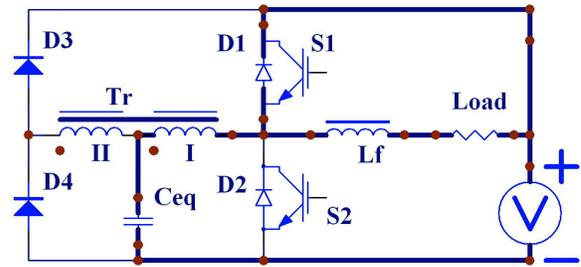


Fig.5 Time t1-t2

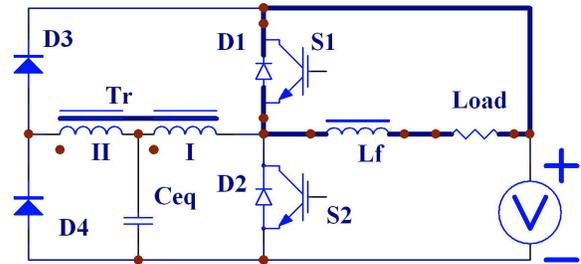


Fig.6 Time t2-t3

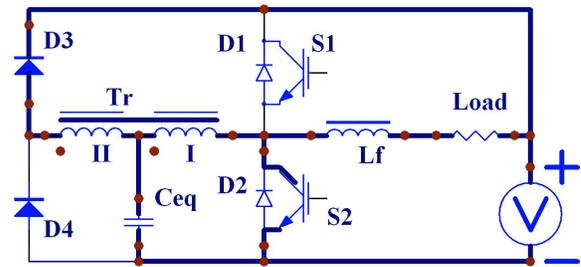


Fig.7 Time t3-t4

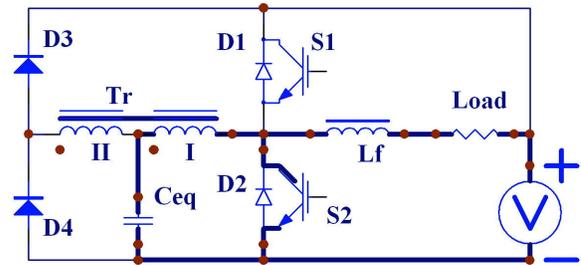


Fig.8 time t4-t5

At t_1 the voltage across S_2 reaches a maximum i.e., V and capacitor C_{eq} stops charging at the full current of L_f , because the shunting of the first winding of the transformer by the secondary stops. At t_1 the voltage across the capacitor reaches

$$V_C = \frac{V}{1+N}$$

The duration of time period t_0-t_1 is determined by the current from L_f , the value of C_{eq} and the voltage V . Between t_1 and t_2 (Fig.5) the fly back process of the current from L_f continues through diode D_1 . During this period the capacitor C_{eq} is being charged by the magnetizing current of the primary winding of the transformer, which is small. Between t_2 and t_3 (Fig.6) the fly back of current from L_f continues and the snubber circuit state remains the same. At t_3 switch S_2 turns on. The new cycle of power conversion is beginning along with the discharge process of the capacitor C_{eq} . Most of the energy from the capacitor will discharge between t_3-t_4 (Fig.7) and return to the source. This happens because the capacitor is connected across the primary winding of the transformer via S_2 , the secondary winding is connected via D_3 to the source. The value of the current via primary winding (I_1) will be determined by the impedance of the winding (including leakage inductance), diode and capacitor. This process will stop when the voltage across the capacitor reaches

$$V_C = \frac{V * N}{1+N}$$

This process is analogous to the process between t_0 and t_1 and will stop at t_4 . The time between t_3-t_4 can be calculated by the

$$\text{formula } t = \frac{V_C * C_{eq}}{I_1(1+N)}$$

At t_4 (Fig.8) the capacitor will start to discharge via the magnetizing inductance of the primary winding of the transformer with a low level of current and stop discharging at t_5 . The process between t_4 and t_5 is analogous to the process between t_1-t_2 . When switch S_1 provides power conversion the behavior of the snubber circuit will be identical to the one where S_2 provides power conversion. The practical waveforms will be different from theoretical ones because all semiconductors have body capacitance and real switching time (none zero), additionally all components have real impedance. The proposed snubber has been tested on a half-bridge DC-AC converter with a 120VAC output voltage, 6kW nominal power, and 12kW surge (Fig.9) with ZCS turn-on.

The new snubber improves efficiency by around 1% and reduces slew rate when S_1 and S_2 turn off (Fig.10 and Fig.11) Where: channel 1 shows the waveform across S_2 , channel 2 shows the waveform at point "b" and channel 4 shows the current waveform at point "a", test conditions are: 420VDC supply voltage 70A load). Efficiency comparisons at 420VDC input.

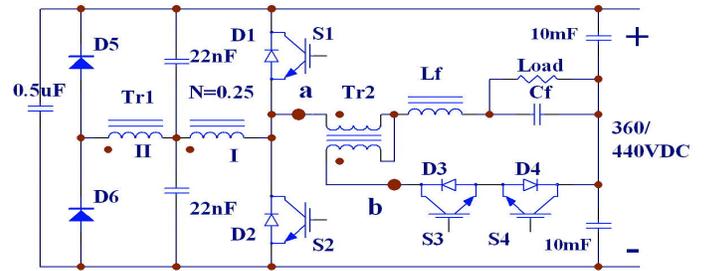


Fig.9 The proposed snubber with DC-AC converter 120VAC output

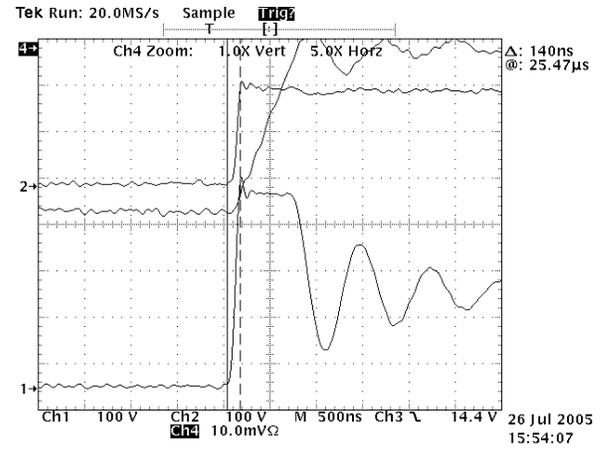


Fig.10 Waveforms of DC-AC Converter without snubber, Rise time 140ns Channel 4 20A/div

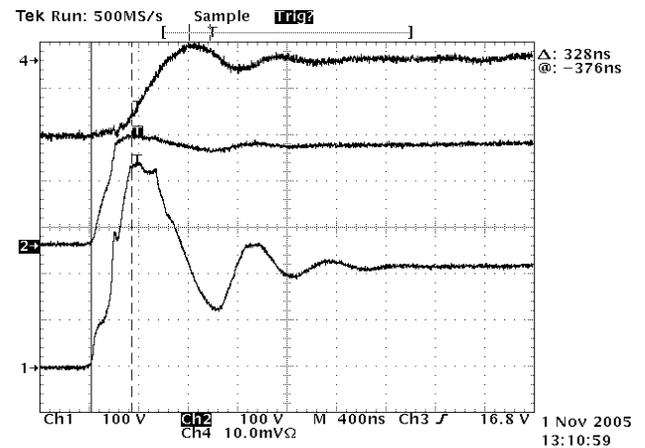


Fig.11 Waveforms of DC-AC Converter with snubber Rise time 328ns Channel 4 50A/div

P _{out}	Without Snubber	With Snubber
6.2kW	96%	96.8%
10.6kW	95%	96%

Fig.11 Table- Efficiency comparisons at 420VDC input.

III. CONCLUSION

The proposed snubber circuit is absolutely symmetrical, it provides ZVS turn off commutation and has about a 75% recovery of snubber capacitor energy to the source. The controlled rise time will also improve electromagnetic emissions and the ZVS turn-off may allow a lower voltage or SOA rated device to be used. This snubber circuit is suitable for use with standard IGBT modules. The performance of an inverter can be better if this new snubber circuit is used in conjunction with a ZCS turn on circuit (as used by the authors, or as in[10], or many other types of inverter). The symmetry of this snubber allows use of it in buck and boost converters also. In other words, this circuit has a very wide range of potential applications

REFERENCES

- [1] C.Turpin, F.Forest, F.Richardeau, T.A. Meynard and A.Lacarnoy "Switching Faults and Safe Control of an ARCP Multicell Flying Capacitor Inverter" *IEEE Transactions on Power Electronics*, 18 (5) pp.1158-1167, 2003
- [2] K.Shiraishi, K.Imamura, Y.Fujii, M.Nakamura, T.Ahmed, M.Nakaoka and H.W.Lee "Active Auxiliary Resonant Snubber-Assisted Soft-Switching PWM Inverter with Optimum Gate Pulse Pattern Sequences and Its PV-System Application" *IEEE PESC 2004* pp.3971-3977
- [3] Y.P.Li, F.C.Lee and D.Boroyevich "A Simplified Three-Phase Zero-Current-Transition Inverter with Three Auxiliary Switches" *IEEE Transactions on Power Electronics*, 18 (3) pp.802-813, 2003
- [4] B.W.Williams "Power Electronics. Devices , Drivers and Applications" *Macmillan, London, 1987*
- [5] C.L.Chen and C.J.Tseng "Passive lossless snubbers for DC/DC converters" *IEEE Proc.-Circuits, Devices and Systems*, 145 (6) pp.396-401,1998
- [6] Jin He "An Improved Energy Recovery Soft-switching Turn-on/Turn-off Passive Boost Snubber with peak Voltage Clamp" *IEEE APEC 2000* pp.699-706
- [7] X. He, S. J. Finney, B. W. Williams and Z. Qian "Novel Passive Lossless Soft-clamped Snubber for Voltage Source Inverter" *IEEE APEC 1996* pp.200-206
- [8] S.J.Fenney, B.W.Williams and T.C.Green "RCD Snubber Revisited" *IEEE Transactions on Industry Applicationc*, 32(1) pp.155-160, 1996
- [9] Patent 5,260,607 US Nov.9, 1993 Snubber circuit for power converter
- [10] S.J.Finney, D.J.Tooth, J.E.Fletcher and B.W.Williams "The Application of Saturable Turn-On Snubbers to IGBT Bridge-Leg Circuits" *IEEE Transactions on Power Electronics*, 14 (6) pp.1101-1110