IMPROVEMENTS TO THE PASSIVE LOSSLESS SNUBBERS FOR POWER BRIDGE LEGS*

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Abstract The paper considers three common snubber circuits used on gate turn-off thyristor and/or insulated gate bipolar transistor inverters. The three snubbers are passive lossless circuits for power bridge legs, and the improvements and modifications to these snubber circuits are presented. The comparative features and operation of the three improved energy recovery snubbers are discussed and supported by PSPICE simulations and experimental results.

Key words Snubber; Inverter; Thyristor; Transistor

I. Introduction

High power Gate Turn-Off (GTO) thyristor inverters incorporate both turn-on and turn-off snubbers as essential circuitry. The capacitive turn-off snubber, $C_s$ is necessary for safe GTO turn-off. An inductive turn-on snubber, $L_s$ not only controls GTO $di/dt$, hence turn-on loss, but also controls freewheel diode reverse recovery. As the DC rail voltage, $V_{DC}$, increases, the switching frequency is reduced in order to decrease losses, since high voltage devices switch slower and have higher on-state voltages. Also, adversely, turn-off snubber losses increase with the square of voltage, according to $C_s V_{DC}^2/2$. Hence at high voltages, significant turn-off snubber energy needs to be dissipated.

The selection of the turn-on snubber inductor is usually based on a GTO initial $di/dt$ and the DC supply rail, according to $V_{DC} = L_s di/dt$. Snubber energy to be dissipated is independent of rail voltage and dependant on maximum load current according to $L_s I_m^2/2$. The total energy dissipated in the three legs of a three-phase inverter including diode reverse recovery $I_r$ is given by

$$ W_t = \frac{3}{2} \left[ C_s V_{DC}^2 + \frac{1}{2} L_s I_m^2 + L_s I_r^2 \right] \quad (J) \quad (1) $$

Although the standard method for the reduction in turn-off loss in a power device is the use of a parallel snubber capacitor, the presence of the snubber capacitor for an insulated gate bipolar transistor (IGBT) also modifies the current fall characteristics. The initial current fall becomes slower and the tail current is significantly increased. These effects were observed for some IGBTs\textsuperscript{1}. In order to increase the ratings of a given IGBT, it is not desirable to use a turn-off snubber, and the use of a turn-on snubber is a distinct

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possibility[2]. The turn-on snubber, the same as in GTO inverters, not only reduces IGBT turn-on losses but also reduces those losses caused by diode reverse recovery.

Numerous inverter turn-on and turn-off snubber circuits have been proposed[3–6]. But with development of power semiconductor devices and active resonant soft switching techniques those passive lossless snubbers would be attractive and applicable in high power and multi-level inverters rather than in small and medium power converters. Three typical inverter passive snubber energy recovery circuits are further discussed in the paper. The McMurray snubber[5] minimises the number of components, but suffers from recovery transformer saturation problems. The Holtz snubber[4] alleviates the saturation problem at the expense of increased component count. The He snubber[5] is a soft-clamping turn-on configuration for IGBT inverters.

II. Snubber One

The first circuit considered for power bridge legs is the McMurray inverter leg recovery snubber shown in Fig.1(a). Advantageously, this snubber provides direct capacitive snubbing across both inverter leg GTOs. In achieving a low snubber circuit component count, recovery is such that both the turn-on and turn-off snubbers are highly interactive. The resistor \( R_s \) damps interaction and minimally reduces recovery transformer reset time. The main problem with this snubber is transformer core reset, which limits operation to a few hundred Hertz. Transformer reset occurs through two diodes and the turn-on inductor.

At a low operating frequency, the loss in the damping resistor exists and the instantaneous peak energy is high. These losses due to snubber interaction can be reduced by the interaction decoupling circuit shown in Fig.1(b). The recovery transformer is connected so as to decouple interaction between the snubbers. Transformer reset is improved by the extra diodes in the reset path, whilst recovery is virtually unaffected. The component count is the same as the McMurray circuit, but without any resistive losses.

The PSPICE simulations are performed and the only respective experimental waveforms for both snubbers in Fig.1 are given in Figs.2(a) and 2(b), where the voltage waveforms at turn-off of the bottom switch SW2 are given and the high frequency ringing on \( V_{sw2} \) and \( I_{Drs} \) are caused by transformer leakage inductance, line inductance and capacitance in the practical circuit. In Fig. 2(b) the same transformer is used except that it is centre tapped so as to accommodate and facilitate the interaction decoupling and rejection circuit. The transformer secondary current \( I_{Drs} \) is shown. The circuit parameters in the simulations and experiments are

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\begin{align*}
L_{s1} &= L_{s2} = 9\mu H, \quad C_{s1} = C_{s2} = 0.1\mu F, \quad R_s = 3.3\Omega, \\
N_{ts}/N_{tp} &= 5 \text{ (turn's ratio in Fig.1(a))}, \\
N_{ts}/N_{ts} &= N_{ts}/N_{t2} = 5 \text{ (turn's ratio in Fig.1(b))}. 
\end{align*}
\]

The main switches used here are IGBTs in order to confirm circuit operational processes at \( V_{DC}=300V, \quad I_m=22A \).

III. Snubber Two

The basic Holtz snubber is shown in Fig.3(a), while the modified circuit showing a multiple transformer secondary circuit is shown in Fig.3(b). Although the Holtz snubber uses more components than the McMurray circuit, it does provide independence and control of the reset mechanisms and does alleviate transformer core reset problems. Minimal interaction