Flyback type Snubber Circuit with di/dt Limiting Capability for IGCT in MV Wind Turbines

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ABSTRACT

Converters employing IGCTs usually require di/dt snubber and Over Voltage Protection (OVP) circuit for the protection of IGCTs and fast diodes. In these IGCT-based converters, conventional di/dt snubber and OVP circuit dissipates a significant amount of power loss. To reduce this loss of conventional di/dt snubber and OVP circuit, this paper proposes a flyback type snubber circuit with di/dt limiting characteristic for IGCT-based converters in medium voltage wind turbines. This flyback type snubber circuit simply consists of a flyback type transformer and diode. The proposed circuit reduces loss and simplifies conventional di/dt snubber by adopting the flyback type transformer. Loss analysis of conventional di/dt snubber and OVP circuit is performed for the 3-level NPC type back-to-back VSC supplied from grid voltage of 6.9kV. The proposed flyback type snubber circuit can save the loss of conventional snubber circuit in the 3L-NPC type back-to-back VSC in multi-MW MV wind turbine. The proposed snubber circuit has a fewer number of components and improved efficiency leading to a reliable and efficient wind turbine systems.

1. Introduction

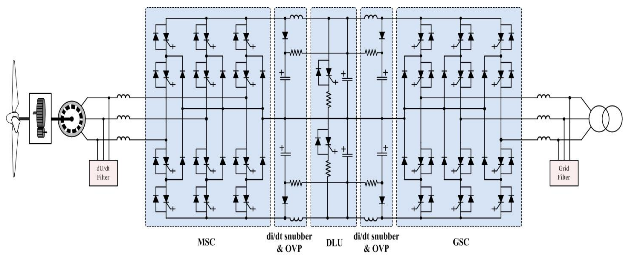


Fig. 1 Overall scheme of PMSG wind turbine system with a back-to-back 3L-NPC VSC.

In the multi-MW wind turbine market, the maximum power rating of a commercial wind turbine has been increased more than 5MW with a view to generate more power from wind power sites [1]. In the family of Multi-Level (ML) inverters, the three-level (3L) topology, called Neutral Point Clamped (NPC) inverter, is one of the few topologies that has received a reasonable consensus in the high power community [3]. These NPC inverters have been implemented successfully in the industrial applications for high power drives and wind turbines [4]. As the most commercialized ML converter, PMSG (Permanent Magnet Synchronous Generator) wind turbine system with a back-to-back 3L-NPC VSCs is presented in Fig. 1.

Today 3.3, 4.5, and 6.5kV IGBTs (modules or press packs) and 4.5, 5.5 and 6.5kV IGCTs (press pack only) are applied in newly developed industrial 3L NPC-VSCs. Converters employing IGCTs require a small clamp inductor which limits short-circuit peak currents and the di/dt during IGCT turn-on transients to enable diode turn-off transients within the Safe Operating Area (SOA), as well as homogenous IGCT turn-on transients. To achieve output voltages of 6-7.2kV, a series connection of two or three devices per switch position or a single device with higher blocking voltage is required. To enable an extension of the converter-voltage range, efficient concept for a series connection of IGCTs was recently developed [6]. Alternatively to a series connection of IGCTs, 10kV IGCTs have been developed and successfully tested, which enable converter voltages of 4.16kV-7.2kV without a series connection of devices [6]-[11].

The integration of one 10-kV IGCT and one fast 10kV diode is a very attractive solution for converters since the expense for the mechanical construction and cooling can be substantially reduced. This medium voltage drive employing 10kV IGCTs needs a di/dt limiting inductor to meet the required di/dt characteristics during switching on transients. This di/dt limiting inductor usually necessitates an additional Over Voltage Protection (OVP) snubber or clamping circuitry as shown in Fig. 1. Thus this snubber circuitry dissipates additional power loss and gives a rise to an important loss factor. There have been several kinds of active RCD snubber for GTO device trying to meet both wide SOA and low loss [12]-[17]. However those snubber circuitries add device count and circuit complexity.

In this paper a new flyback type snubber circuit which is simpler and more efficient than conventional RCD snubber for 10kV IGCT in MV Wind Turbines is proposed. This flyback type snubber is adopting a flyback type transformer. The proposed type snubber circuit is very effective in the restriction of the di/dt characteristics. In addition, also the power loss caused by OVP circuit is reduced significantly.

2. Flyback type Snubber Circuit for IGCT

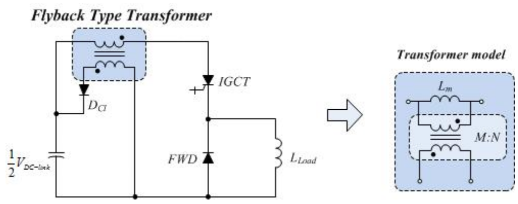


Fig. 2. Flyback type snubber circuit for IGCT in the upper-half part of 3L-NPC VSC.

The proposed flyback type snubber configuration is shown in Figure 2. One converter phase leg circuit is considered for the sake of simple analysis. Converters employing IGCTs need a di/dt limiting inductance to meet the required di/dt characteristics during switching on transients. Thus, the proposed flyback type snubber circuit adopts flyback type transformer instead of L_i to provide di/dt limiting characteristic of IGCT. Most distinguished advantages are decreased loss and simpler OVP clamp circuit. Magnetizing inductance of flyback type transformer plays an effective role for meeting the di/dt limiting characteristics at IGCT.

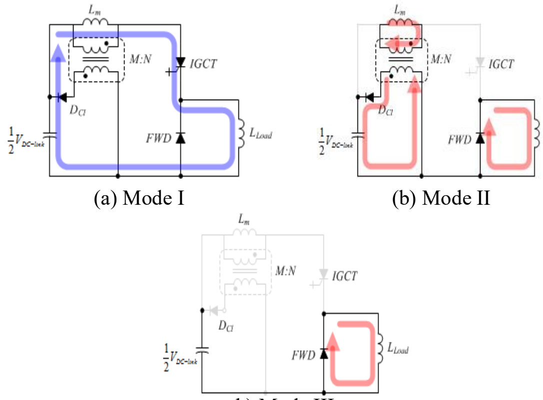
3. Flyback type snubber circuit operation for IGCT

There are three operating modes in one switching period.

(1) ***Mode I [t_1]:*** During this mode, IGCT is turned on. Freewheeling diode (FWD) and clamp diode (D_{Cl}) are turned off. Before the IGCT turns on, the load current I_L is freewheeling through the FWD. The value of the magnetizing inductance L_m is selected for *di/dt* characteristics of IGCTs.

(2) ***Mode II [t_2]:*** During this mode, IGCT is turned off. FWD and D_{Cl} are turned on. The magnetizing inductance L_m releases the trapped energy to secondary side, and the current of magnetizing inductance (i_{Lm}) is decreased.

(3) ***Mode III [t_3]:*** During this mode, IGCT and D_{Cl} are turned off. FWD is remained to be turned on. When the current of magnetizing inductance (i_{Lm}) becomes zero, the clamp diode is turned off. Load current (I_L) is freewheeling through the FWD.



(a) Mode I (b) Mode II

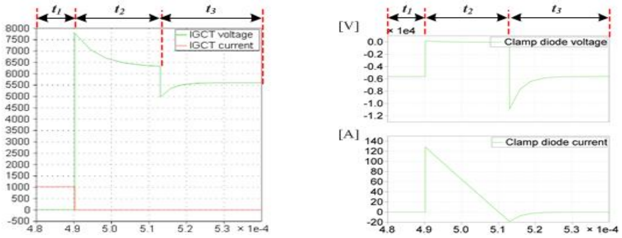
b) Mode III

Fig. 3. Current-flow path of flyback type snubber circuit.

4. Simulation Results of Flyback type Snubber Circuit

A. Simulation results of flyback type snubber circuit

The waveforms of voltage and current during the IGCT's switching transient process are shown in the Fig. 4. There are two switching voltage peaks in turn off process of IGCT and clamp diode (D_{Cl}). The voltage overshoot peak (V_{DSP}) of IGCT can be adjusted by the turn ratio of flyback type transformer. Therefore voltage stress of IGCTs can be decreased.



(a) Waveforms of voltage and current of IGCT (b) Waveforms of voltage and current of clamp diode

Fig. 4. Waveforms of voltage and current of IGCT and Diode at each mode.

However, the minimum transient time (t_2) of IGCTs is proportionally increased as the voltage peak of IGCTs is decreased. The reverse voltage peak of clamp diode is almost twice. To prevent the high reverse voltage, clamp diode can be series connected. The forward current flowing through clamp diode is decreased by increasing turn ratio of flyback type transformer. To choose appropriate parameters of flyback type snubber circuit components (e.g., turn ratio of flyback type transformer and clamp diode capacity), it is necessary to consider the peak rating of devices and the transient time of turn off process collectively.

B. Conventional snubber loss of 7MW MV 3L-NPC VSC

Table I. System specifications of 7MW MV 3L-NPC VSCs.

Parameter	Symbol	Value	Per unit
Output power	$P_{rated\text{-}out}$	7 MW	1.0
Grid frequency	f_{grid}	60 Hz	1.0
Grid side inductance	L_{grid}	2.5 mH	0 17
Grid side input voltage	V_{ll}	6.9 kV	1.0
Grid side input current	I_{AC_input}	854 A	1.0
Switching frequency	f_{GSC_PWM}	1020 Hz	-
DC-link voltage	$V_{DC\text{-}link}$	11.2 kV	-
AC filter inductance	L_f	2.3 mH	0 16
AC filter capacitance	C_f	0.22 mF	0.45
di/dt limiting inductance	L_i	13.6 µH	-

The simulation is performed based on the parameters of 7MW MV VSCs as specified in Table I. The selection of switching frequency is done through compromising the switching loss and the harmonic content of ac input current. The simulation is performed based on 10kV IGCTs in each phase-leg during one ac line period under the power factor of 0.9 leading condition. The converter operates under the inverter mode, i.e. power flows from the converter into the grid. In order to compare the conventional snubber losses for the worst cases, the simulation has been performed under the condition of maximum ac input current; line under-voltage of 90% and power factor of 0.9 leading condition.

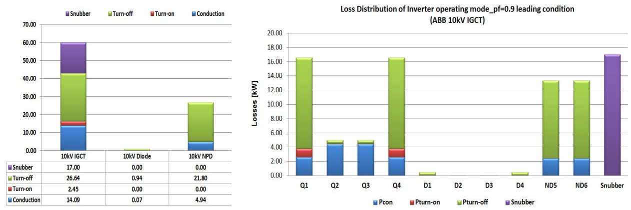


Fig. 5. Total loss distribution in 7MW MV 3L-NPC VSC.

The power losses of di/dt snubber and OVP clamp circuit for IGCT in 7MW MV 3L-NPC VSCs have been summarized in Fig. 5 under 0.9 leading power factor condition. The total loss of the conventional snubber circuitry is obtained to be around 17kW for a grid side converter. Proposed flyback type snubber can save the loss value of 34kW for di/dt snubber and OVP circuit in a 7MW back-to-back VSC neglecting core losses.

5. Conclusion

In this paper flyback type snubber circuit for 7MW PMSG wind turbine employing a 3L-NPC back-to-back voltage source converter is presented. The proposed flyback type snubber circuit using a flyback type transformer has superior features such as fewer number of snubber component and improved efficiency due to reduced loss of conventional snubber. The 10kV IGCT for the voltage classes of 6- to 7.2-kV MV 3L-NPC VSCs is investigated and basic operation of the flyback type snubber circuit is verified. The proposed flyback type snubber circuit can save the loss of conventional snubber circuit in 7MW back-to-back 3L-NPC VSC that falls into the range of 34kW, approximately.

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