REDESIGN OF THE H-BRDIGE SWITCH PLATE OF THE SNS HIGH VOLTAGE CONVERTER MODULATOR*

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Abstract

The 1-MW High Voltage Converter Modulators [1] have operated in excess of 250,000 hours at the Spallation Neutron Source. Increased demands on the accelerator performance require increased modulator reliability. An effort is underway at SLAC National Accelerator Laboratory to redesign the modulator H-bridge switch plate with the goals of increasing reliability and performance [2]. The major difference between the SLAC design and the existing design is the use of press-pack IGBTs. Compared to other packaging options, these IGBTs have been shown to have increased performance in pulsed-power applications, have increased cooling capability, and do not fragment and disassemble during a fault event. An overview of the SLAC switch plate redesign is presented. Design steps including electrical modeling of the modulator and H-bridge, development of an integrated IGBT clamping mechanism, and fault tests are discussed. Experimental results will be presented comparing electrical performance of the SLAC switch plate to the existing switchplate under normal and fault conditions.

SYSTEM DESCRIPTION

A simplified diagram of the Spallation Neutron Source (SNS) High Voltage Converter Modulator (HVCM) power flow is shown in Figure 1. There are various configurations of the modulators at the SNS that produce between 69 kV to 140 kV. The IGBT switching voltage is up to 2200V, with peak currents up to 2500A. The switching frequency is 20 kHz. The peak power to the load is up to 15 MW and average power is up to 1 MW.

MECHANICAL DESIGN

Press-pack IGBTs were chosen to replace the flat-pack IGBTs in the existing modulator. Press-pack IGBTs have several advantages, including:

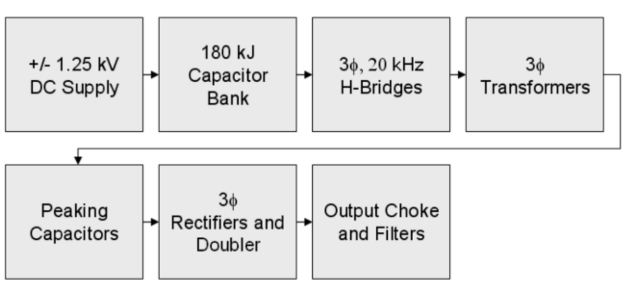

Figure 1: SNS HVCM power flow diagram.

- Increased voltage margin, from 3.3 kV to 4.5 kV. At the time of the design, 4.5kV, 1.2 kA IGBTs were only available in press-pack packaging.
- Press-pack IGBTs can be cooled on both sides of the die. This aids in heat removal.
- Press-pack IGBTs have been shown to have increased reliability in pulsed-power applications [3].
- In a fault event, the press-pack package will not fragment. IGBT fragmentation in the existing switch plate has in some cases resulted in collateral damage.

Because of the packaging differences between the flat-pack and press-pack IGBTs, a redesign of the mounting hardware for the devices was necessary. The existing and SLAC-designed switch plates are shown in Figures 2 and 3 respectively. During the redesign, care was taken to minimize the hardware alterations to the switch plate.

The two largest challenges in redesigning the switch plate were to incorporate the press-pack package clamping and minimizing the effects of lead inductance. The press-pack devices require a 30 kN (3700 lbf.) force

Figure 2: Existing H-bridge switch plate on SLAC test stand.

Figure 3: SLAC designed press-pack switch plate.

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applied evenly across the electrode faces. In press-pack packages, the clamp force is typically applied to the center of a large force spreader. This is not easily achievable with the SNS switch plate because of insufficient space.

After the clamps were designed and built, the clamping force was measured using Fuji Prescale film [4]. Aberrations were compensated by placing shims under the heat sinks. A pressure profile resulting from this study is shown in Figure 4. As shown, the pressure is azimuthally symmetric around the surface of the device. To verify the magnitude of the force applied to the device, the calibrated pressure profile was spatially integrated. For all devices, the measured force falls within manufacturer's specifications.

Lead inductance plays a roll in both the transient characteristics during turn-on and turn-off (such as overshoot) as well as device performance during a fault condition. In general, high inductance in the commutation path will lead to a larger overshoot. However, in some conditions large inductance can be beneficial in limiting the rate of rise of current during a fault condition. Finite element calculations indicate that the effective inductance in the nominal conduction path was increased slightly with the press-pack switch plate. However, the inductance

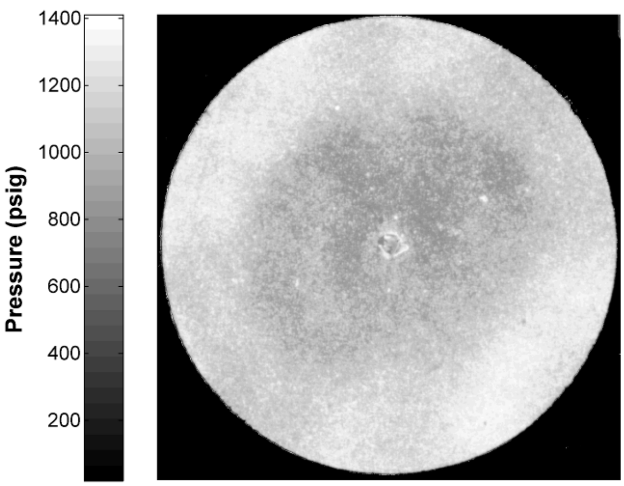

Figure 4: Measured pressure profile on the top surface of press-pack IGBT.

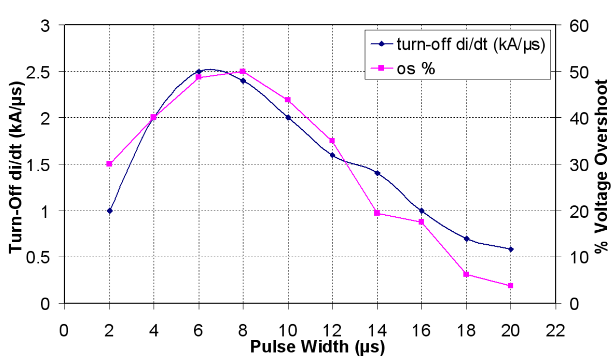

Figure 5: Measured turn-off di/dt for the press-pack IGBT at a capacitor charge of +/- 400V. The di/dt magnitude correlates with the percentage voltage overshoot (OS).

in the shoot-through path was increased by a large amount [5].

SWITCHING WAVEFORMS

One effect of lead inductance is shown in Figure 5. It was found that for shorter pulses, the collector current turn-off was much quicker. This is consistent with the characteristic of drift regions in power IGBTs. As the device turns on, charge is injected into the drift region, gradually reducing the IGBT resistance. A drift region full of charge turns off slower than a drift region which is not full of charge [6]. Therefore, short pulses result in an IGBT that quickly snaps off. Due to the inductance in the commutation path, the high di/dt increases the voltage overshoot. Proper sizing of the gate turn-off resistance partially mitigates the effect by increasing the turn-off time.

A long current tail on turn-off is characteristic of power IGBTs. This has the undesirable effect of increasing turn-off losses. A comparison between two different IGBTs is shown in Figures 6 and 7. The CM1200HB66H power-pack IGBT has a smaller tail than the press-pack IGBT, T1200EA45E. This is consistent with the fact that a higher-voltage device typically has a larger drift region. However, by tailoring of the drift region characteristics, it is possible to minimize switching losses at the expense of increased conduction losses. Identification of vendors to supply devices tailored to the SNS application is ongoing. One effect of increased losses, device heating, may be partially mitigated by the improved heat removal in the press-pack package.

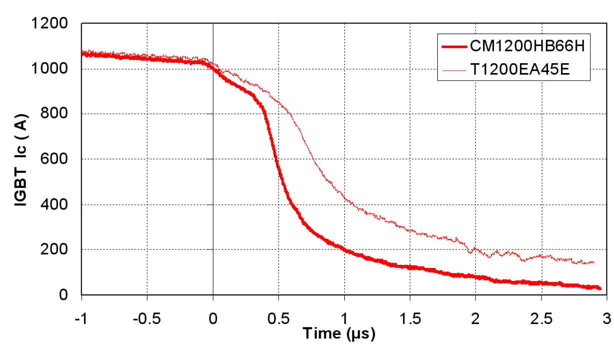

Figure 6: Comparison of the turn-off Ic waveforms for two different IGBTs.

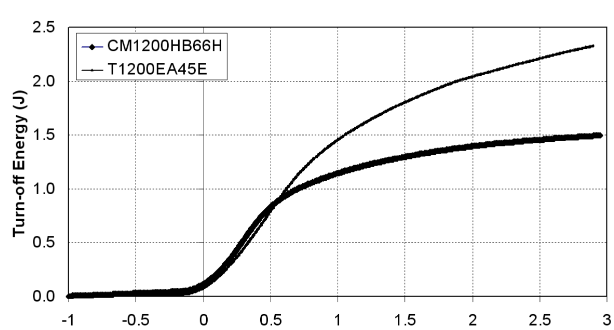

Figure 7: Comparison of the turn-off energy waveforms

FAULT TESTS

Several fault tests were performed on both the existing switch plate and the press-pack switch plate on the SLAC single-phase test stand. The goal was to test the performance of the SLAC-designed gate driver on each of the switch plates [7]. Fault tests included a transformer primary arc-down and transformer saturation. In the event of either of these faults, the gate drive should quickly detect the fault and shut-down the IGBT before the current rises to an unacceptable level.

Both switch plate versions survived the fault tests. The newly-developed gate drive was able to quickly detect and control the IGBTs during the faults. However, it was noted that, during an arc-down test, the press-pack switch plate had around a 25% lower di_c/dt from the time of arc inception to IGBT commutation [5]. Low di/dt is necessary to retain control of the IGBT via the gate. Therefore, during more stressful fault scenarios, the press-pack switch plate may prove advantageous. The lower di/dt is attributed to higher inductance in the shoot-through path as well as differences between IGBTs. It is also noted that at no time during the testing and development of the press pack switch plate did the IGBTs fragment.

ONGOING WORK

The press-pack switch plate has been designed, manufactured, and tested to peak power. There are several tasks that are still ongoing:

- The effects of IGBT turn-off at low current are being studied. There are three modulator configurations at the SNS. Each of these “tunings” has different IGBT switching characteristics. The initial switch plate testing was based on the highest power configuration. Additional testing will demonstrate operation over the full range of tunes.
- Full average power tests are underway. Switching loss and performance will be compared to the existing devices.
- Alternative sources of press-pack devices are sought, with switching characteristics better suited to the HVCM application.

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