CONVERTER-MODULATOR DESIGN AND OPERATIONS FOR THE "ILC" L-BAND TEST STAND*

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Abstract

To facilitate a rapid response to the International Linear Collider (ILC) L-band development program at SLAC, a spare converter-modulator was shipped from LANL. This modulator was to be a spare for the Spallation Neutron Source (SNS) accelerator at ORNL. The ILC application requires a 33% higher peak output power (15 MW) and output current (120 Amp). This presents significant design challenges to modify the existing hardware and yet maintain switching parameters and thermal cycling within the semiconductor component ratings. To minimize IGBT commutation and free-wheeling diode currents, a different set of optimizations, as compared to the SNS design, were used to tune the resonant switching networks. Additional complexities arose as nanocrystalline cores with different performance characteristics (as compared to SNS), were used to fabricate the resonant "boost" transformers. This paper will describe the electrical design, modelling efforts, and resulting electrical performance as implemented for the ILC L-band test stand.

INTRODUCTION

The converter-modulator that was sent from LANL to SLAC was the first article 140 kV, 72 Amp modulator produced by Dynapower Corporation in Burlington, Vermont. This unit operated for about 6,000 hours with perhaps 4,000 hours at full peak and average power. This unit was used to acceptance test the Thales 5 MW (RF output), 805 MHz klystrons. To accommodate the 33% higher klystron beam pulse (15 MW) for the ILC 1.3 GHz klystron, changes were needed to squeeze the last bit of performance capability of the IGBT switching and resonant rectification networks. The ILC tube requires 125 kV at 120 amps, almost a factor of 2 lower beam impedance than the SNS design. This change in klystron beam load impedance requires significant changes in the resonating networks, the required peaking capacitance, filter doubler capacitance, and boost transformer leakage inductance. This is necessary to ensure IGBT zero-voltage-switching (ZVS) at turn-on and to also minimize IGBT commutation current.

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Minimal commutation is desired to reduce free-wheeling diode current in the totem-pole connected IGBT. Excessive diode current can lead to longer turn-off times from increases in junction temperature, which then can result in forced commutation and run-away conditions, that can lead to energetic failures. There were also concerns related to the resonant rectification networks. The rectification currents at 20 kHz were approaching the capabilities of the fast recovery diodes. After lengthy discussions at SLAC, we agreed that the diode performance was sufficient for this application. Other components requiring modification or changing were the output filter choke and output de-Q resistor.

SYSTEM FABRICATION

To implement these changes LANL modelled the ILC performance requirements utilizing the converter-modulator data from the SNS operations. However, to facilitate production of the new nanocrystalline boost transformers for SLAC, the only core material easily available was the VacuumSchmelze Vitroperm 500. This core material was surplus from the Los Alamos prototyping efforts and is different than the SNS production run that used Hitachi "FT-3". The Vitroperm 500 has a lower "mu" (25,000 vs 50,000) and a lower stacking factor, ~75% vs ~90% for the FT-3.

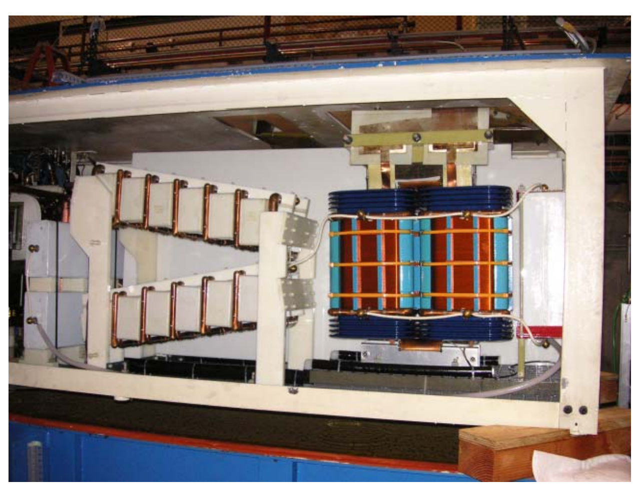

Figure 1: View of resonating capacitor, nanocrystalline boost transformer, and resonant rectification assembly

The stacking factor is the more important parameter in the determination of the transformer leakage inductance, a critical element for appropriate IGBT switching parameters. In Figure 1, from right to left, depicts the resonating capacitors, the nanocrystalline boost transformer assembly, and the resonant rectification assemblies. The resonating capacitor can be noted as being directly connected in parallel with the transformer. To achieve the appropriate leakage inductance for tuning, new boost transformers were designed and fabricated at LANL. To achieve the appropriate peaking and circuit "Q" for the ILC klystron, LANL also provided new resonating capacitors and voltage doubler capacitors.

To avoid saturation of the output filter choke, th e modification was simple. By removing the appropriate number of turns this ensures the volt-second ratings of the choke were not exceeded. The other modification of the output filter network was to reduce the output series resistance to ~ 2 Ohm. These resistors absorb the system stored energy when the klystron arcs-down. The output filter changes do not sacrifice the klystron fault energy and the reduced values provide a faster rise-time with minimal overshoot. The resonant rectification assemblies, doubler capacitors, and output filter choke can be noted in Figure 2, from right to left. Other assemblies can be seen, the small assembly with the corona rings is a harmonic trap network that minimizes bleed-through of higher order switching harmonics.

Figure 2: View of doubler capacitors and output filter choke

The 3-phase polyphase IGBT switch plate assemblies, noted in Figure 3, operate with high dynamic stresses to achieve the 15 MW output requirements of the ILC tubes. This parameter space fortunately is at low repetition rate (5 Hz) and therefore with little overall heating to the IBGT's. So far the system has been reliable, with only a failure of an IGBT drive card. At higher average power "dual" IGBT switch plate assemblies would be desired and "pentaphase" converters could be utilized to drive a pair of ILC klystrons with minimal dynamic stresses. Furthermore, advanced tuning techniques [1] can be utilized that reduce overall IGBT switching losses and further increase overall converter-modulator efficiency, perhaps to 96%. Improved efficiency is an important consideration for system operating at high average power or where utility costs are a concern.

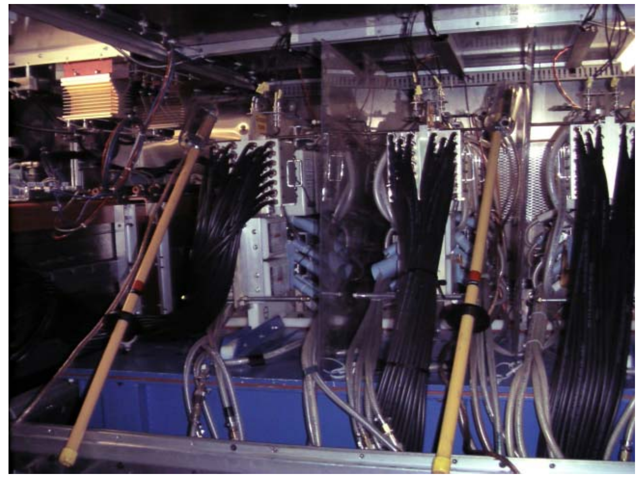

Figure 3: IGBT switching assemblies

OPERATIONS

The converter-modulator, as shown in Figure 4, was installed on schedule at SLAC. The installation is different from those at LANL and ORNL. Access to the modulator tank internals at SLAC must be accomplished in-situ. LANL and ORNL air-pad the modulator from beneath the safety ensclosure for access to the internals. SLAC must lift the safety enclosure and because of earth quake concerns, the modulator is bolted to the floor.

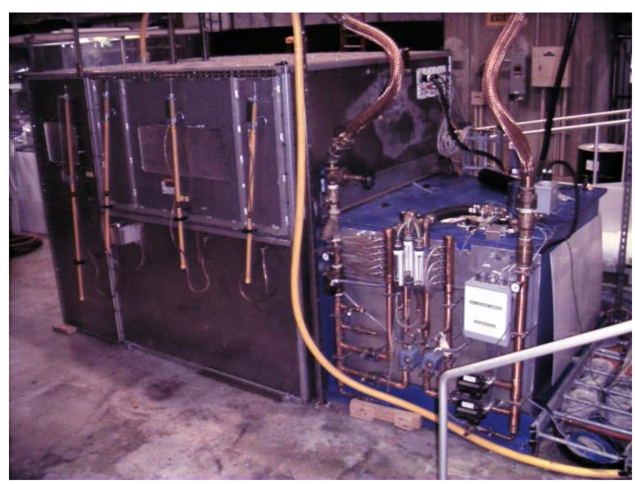

Figure 4: 15 MW output converter-modulator

Once installed, the converter-modulator operated a dummy load and tests were made to ensure that arc-down energy at the required operational voltages and power level were within specification. These initial turn-on and debug tests cleared the system for operations with the klystron being used for the ILC RF system evaluations, a Thales TH2104C. Operation with this tube continues and a comparison transformer drive voltage was made as compared to that modelled. The modelled and measured performance are quite similar, but differences can be used to better optimize and retune the converter-modulator to match the actual perveance characteristics of the klystron and applied link voltage. The differences in the modlled transformer drive waveforms as those measured during operation is provide in Figure 5.

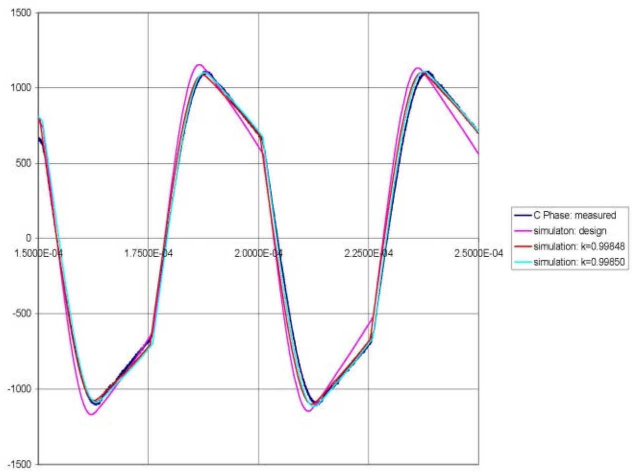

Figure 5: Comparison of modelled and measured results

CONCLUSION

This collaboration has been very beneficial to all participants. SLAC has received a very useful piece of equipment that saved project schedule and budget. LANL has gained further experience in manipulating design trade-offs for various performance requirements, coupled to component capabilities. The ORNL, LANL, SLAC teaming provides a larger experience base to exchange ideas and experiences that will ultimately benefit operations at ORNL.

REFERENCES

[1] W. A. Reass and R.F. Gribble, "Improved Tuning Methods for Converter-Modualtors", PAC07, Albuquerque, NM.