Neutral Beam Power System for Fast Grid Modulation

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Introduction
Neutral beam injection (NBI) is an important tool for plasma heating, current drive and a diagnostic at fusion science experiments around the United States. Producing power systems that can respond rapidly (10 μs) at high voltage (10 to 100 kV) for beam acceleration or high currents (~1 to 5 kA) for control of the ion source is non-trivial. Currently, there are no vendors in the United States for NBI power systems. Eagle Harbor Technologies (EHT), Inc. is developing new solid-state switching power systems for NBI that takes advantage of the latest developments in solid-state switching. EHT has developed a series resonant converter that can be scaled to the power required for NBI at small-scale validation platform experiments. This power system can modulate the injection beam current during a plasma shot, which can lead to improved control over the plasma. Additionally, these modern solid-state supplies can be made smaller and lower cost than previous generations of NBI power systems. We will present the Phase I testing results, including demonstration of current modulation on a neutral beam system.

Neutral Beam Modulation
Neutral beam modulation experiments have been conducted at TEXTOR, MAST, and DIII-D. At TEXTOR, the NBI system apparatus was modulated, while MAST modulated the current source. Recently, DIII-D published results modulating the grid voltage (slow 20 kV/s). The effects included beam torquing, instability supression, increased ion confinement time and improved control of fast ion losses. This new EHT NBI power system can be used to modulate the NBI voltages on even faster timescales.

- Pace, et al. “Control of power, torque, and instability drive using in-shot variable neutral beam energy in tokamaks” Nucl. Fusion 57 (2017) 04600

Circuit Modeling
EHT conducted initially SPICE modeling to optimize the system efficiency, resonant components, switching frequency, and output stages. Modeling was used to identify potential fault conditions in the event that the grids short. The grid driver must be shut off within 3 ms

Testing at EHT Facility
EHT conducted initial short-duration testing of NBI power system into a dummy load at the EHT facility with output modulation. The two different images have different charge voltages and different duty cycle in order to achieve the same output voltage. It can be seen that the lower duty cycle (right image) results in a more triangular circulating current profile and as expected this produces greater ripple on the output.

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Long Duration Resistor Testing
EHT tested the NBI driver with a large capacitor bank into a dummy load at a user facility. The figure shows a 10 kV, 20 ms pulse (purple, 1:1 divider). Ch2 (yellow) and ch2 (blue) are the voltage across the switch and ch4 (green) is the circulating current.

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Conclusion
EHT has built an neutral beam grid power system with the following specs.

- Charge Voltage: 0 – 700 V
- Output Voltage: 0 – 15 kV
- Output Current: 0 – 40 A
- Switch Frequency: 125 kHz
- Pulse Width: 8 μs – 100 ms
- Shot Frequency: 1/min
- Control: External Fiber
- Short Tolerant: Overcurrent requires shut down in 3 μs

EHT is currently seeking funding for the next generation system that could be tested at the Lithium Tokamak Experiment.

Acknowledgment
This work was funded by a DOE SBIR (DE-SC0017792).