Digital Control and Power Systems for the PEGASUS-III Experiment

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The PEGASUS-III experiment is a solenoid-free, low aspect ratio spherical tokamak at the University of Wisconsin-Madison that will serve as a dedicated US platform for comparative non-solenoidal tokamak plasma startup studies. Approximately 175 MVA of reconfigured and expanded programmable power systems and 7 MJ of new stored energy for the facility are being commissioned to support the PEGASUS-III upgrade. These include: a toroidal field increase from 0.15 to 0.6 T; new divertor and poloidal field coils; increased pulse length; local and coaxial helicity injectors for solenoid-free plasma initiation; RF systems for heating and current drive; and a diagnostic neutral beam. A new digital control system using FPGA technology and real-time computing implements 16 PID feedback controllers with 15 kHz loop rates to control the electromagnets and helicity injector systems. The poloidal fields are driven by twenty 3.6 MVA (4 kA, 900 V) IGBT buck converters, backed by 84 kJ/module (~50 ms pulse). Twelve new 3.6 MVA, long-pulse IGBT buck converters for the 48 kA/turn TF are backed by 3 MJ of stored energy. Helicity injector bias current with dynamic injector voltage control will be provided by a set of four new 10.8 MVA CMLI topology systems. Each is comprised of an 1800 V IGCT stage and a $\pm$900 V IGBT stage in series, providing $I_{inj} \leq 4$ kA at $V_{inj}(t) \leq 2.7$ kV. Injector arc current is initially provided by four additional TF buck converters. Tests of an alternate arc driver using Ćuk converters are also under consideration. 0.5 MJ/ injector will provide ~25 ms pulses in initial experiments. An FPGA-based digital fault detection and prevention system validates and multiplexes feedback controller command signals to the ~100 high-power semiconductors in these supplies, simultaneously monitors the ~100 complementary optical status signals, and implements a fast shutdown sequence within 10 μs upon fault detection that minimizes potential collateral damage due to shutdown transients. An 80 kV, 4 A zero-voltage-switching resonant converter with < 1% output ripple is under development for the DNB and is being evaluated as a topology to drive the PEGASUS-III RF sources.

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