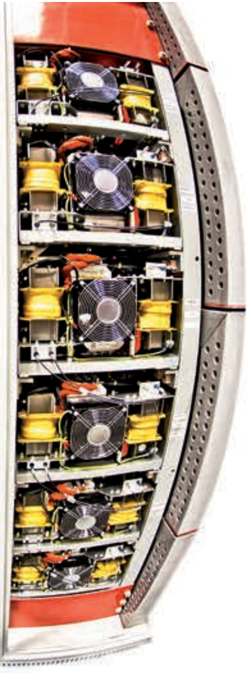
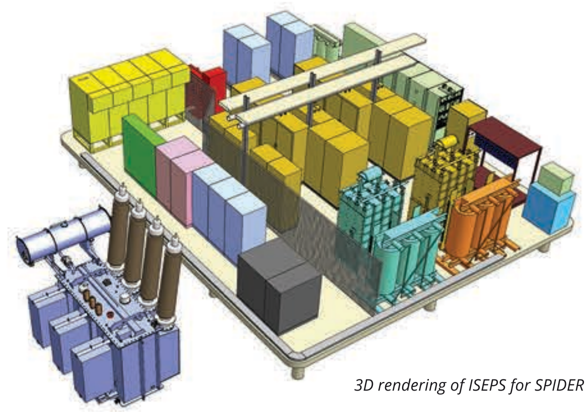


Case Study:
Ion Source and Extraction Power Supplies (ISEPS) for ITER

The International Thermonuclear Experimental Reactor (ITER) is an international research effort aimed at developing fusion as an abundant energy source with low environmental impact. The facility is under construction in Cadarache, France, and will feature an experimental Tokamak reactor. The EU, U.S., China, Japan, South Korea, India and Russia are all participating, with the goal of testing the integrated technologies, materials and physics regimes necessary for commercial production of fusion-based energy in the future.

To achieve fusion on Earth, the plasma where the reaction takes place must be heated to about 150 million degrees Celsius. One of the systems used to achieve these extreme temperatures is the “neutral beam injector,” which injects high-energy particles of the same kind present in the reactor to produce heating. ITER will make use of two neutral beam injectors of 17 MW to create, accelerate and finally neutralize the ions before they enter the plasma.

In the first two stages of the neutral beam injector, the ion source generates a cloud of negative Deuterium ions which are then



3D rendering of ISEPS for SPIDER

extracted using the extraction grid. OCEM Power Electronics was commissioned by the organization Fusion for Energy, which is overseeing Europe’s contribution to ITER, to produce the Ion Source and Extraction Power Supplies (ISEPS) system to power these steps.

The ISEPS Project

The ISEPS project consists of four separate systems: one prototype to test the SPIDER ion source; one prototype installed as part of the full-scale neutral beam injector test system, called MITICA; and two systems, ITER 1 and ITER 2, for each of the neutral beam injectors at the completed ITER facility. Each system is composed of high-voltage power supplies, high-current power supplies, four radiofrequency (RF) generators, a high-performance control and monitoring unit, and all the related subsystems necessary to power and manage the ion source and neutral beam injector.

ISEPS has an overall power rating of 5 MVA and is made up of a heterogeneous set of components, ranging from power distribution equipment at 6.6 kV to high-voltage (up to 12 kV) and high-current (up to 5 kA) solid-state power converters. Each RF generator has a power capacity of 200 kW and an operating frequency of 1 MHz, and is fed by a direct current power supply of 12 kV with a 140A output feed current.

The entire system is hosted inside an air-insulated Faraday cage called the HVD ("high-voltage deck") working at a potential to ground equal to the ions' accelerating voltage.

SPIDER: Source for the Production of Ions of Deuterium

The first ISEPS systems is a prototype for the "Source for the Production of Ions of Deuterium," or SPIDER, experiment, which is a 1:10 scaled

ISEPS main power supplies

prototype for the ITER 1 and 2 systems. The prototype is being tested at the Padova Research on Injector Megavolt Accelerator (PRIMA) facility in Italy, which is dedicated to developing and testing the ITER neutral beam injectors. SPIDER's accelerating voltage is about 100 kV DC compared to 1000 kV DC for the other three ISEPS systems. Its high-voltage deck sits on a raised platform measuring 12 meters by 10 meters, which for purposes of electrical isolation is insulated from the ground and away from any walls.

Factory acceptance tests for SPIDER were successfully carried out at OCEM's headquarters over a three-week period. First, test runs were conducted for each of the major sub-assemblies of ISEPS, followed by power testing of the whole system connected to one of the RF generators supplied by a subcontractor. The power supplies and RF generators were tested at the maximum nominal power of 200 kW for

ISEPS overview

a period of 15 minutes – a longer duration than anticipated in the test plan for such a high power level.

In April 2015, SPIDER was delivered to the PRIMA facility in Padova and installed between June and September. Commissioning, functional tests and site tests took place in October and November, with site tests beginning in December.

SPIDER has allowed OCEM to demonstrate not just its technical expertise but also its project management and integration skills. "OCEM Energy Technology have proven to be highly skilled collaborators and have shown great adaptability in terms of the demanding specifications for ISEPS," Fusion for Energy project team leader Tullio Bonicelli said.

MITICA: Megavolt ITER Injector & Concept Advancement

OCEM has also begun designing the second ISEPS system, the one for the "Megavolt ITER Injector & Concept Advancement," or MITICA. MITICA will include a second full-scale prototype of the ISEPS systems that will be produced for ITER's two neutral beam injectors.

MITICA's acceleration voltage will be 10 times greater than SPIDER's, or 1000 kV. While the SPIDER system's ISEPS is organized on a single level, the MITICA one will be a two-level system on a raised high-voltage deck, with an internal staircase. Like SPIDER, MITICA will be installed in the PRIMA facility in Padova to study and test before the final neutral beam injector systems for ITER are produced.

Unique Characteristics of the ISEPS Project

ITER's neutral beam injectors have several unique characteristics that make ISEPS an especially advanced power system. Each pulse beam has the following specifications:

- Voltage — 1000 kV
- Energy – 17 MW
- Pulse length – 3600 seconds

While most neutral beams injectors only require a pulse lasting a few seconds, ITER's will last for up to an hour at a time. The system's overall performance will be three orders of magnitude higher than existing neutral beam injectors.

MCF control electronics

Source Support Power Supplies cabinet

OCEM POWER ELECTRONICS

ISEPS - Ion Source and Extraction Power Supplies for ITER

SPIDER Components and Specifications

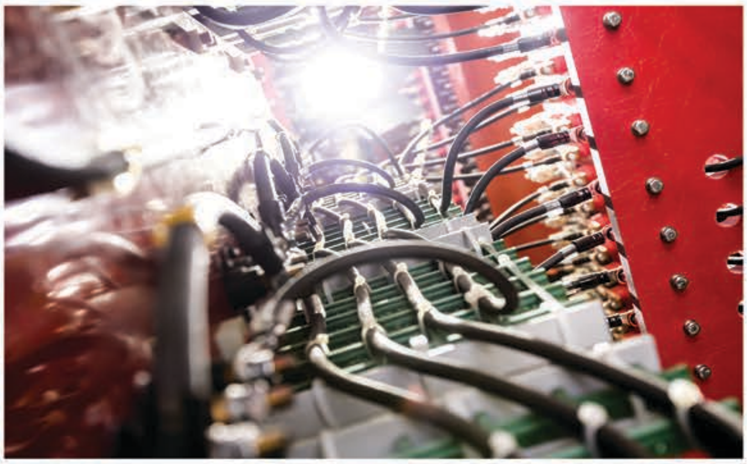
Extraction Grid power system (ISEG)
- Capable of 12 kV at 140 A, voltage ripple < ± 1%

Four radiofrequency generator systems (ISRF)
- Four generators 0.9 ÷ 1.1 MHz, each 200 kW on 50 Ω load (160 kW ± 30° loads)

Source Support Power Supplies power system (ISSS)
- Plasma grid filter power supply, 0÷5000 A, 15 V
- Bias power supply, 600 A, 30 V
- Bias plate power supply,150 A, 30 V
- Two core snubber bias power supplies, 200 A, 50 V each
- Starter filament bias power supply, 4 A, 160 V
- Six Caesium oven power supplies, 4 A, 160 V

Power distribution (ISPD)
- Oil transformer rated 5MVA, 22/6.6kV insulated at 100 kV DC
- Circuit breaker and distribution boards at 6.6 kV and 400 V
- Resin cast transformers (200 kVA / 6.6 kV and 130 kVA / 400 V) to feed the 400 V loads grouped into two insulated subsystems

Local Control systems
- "Slow control system" for configuration, supervision and monitoring of the ISEPS
- "Fast control system" for management of fast controls, feedback regulations and protection functions, interlocking of power system internal faults, and all high-speed communications



Scan the QR Code to watch an interview with OCEM Power Electronics Manager Giuseppe Taddia on YouTube.

About Us

For more than 70 years, OCEM Power Electronics has designed, manufactured and installed power systems for premier research laboratories around the world. Its customized power systems are enabling advances in the fields of plasma physics, particle physics and medical research, and driving advanced industries such as transportation and food processing.

OCEM Power Electronics
a division of Energy Technology Srl

Via della Solidarietà, 2/1
Località Crespellano
40056 Bologna - Italy

+39 051 6656611
power@ocem.eu