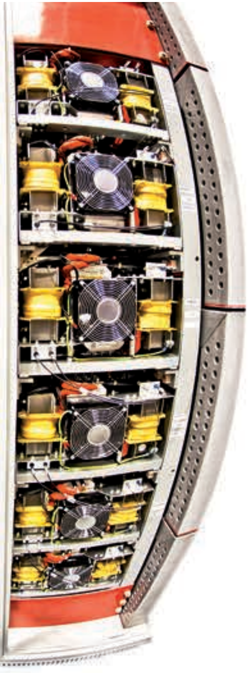
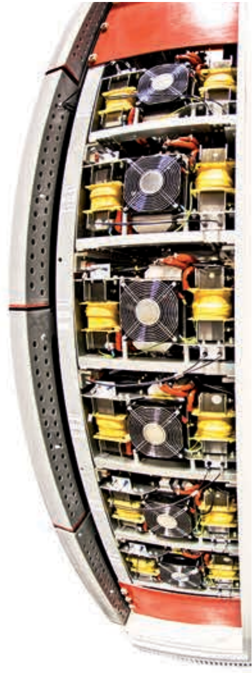


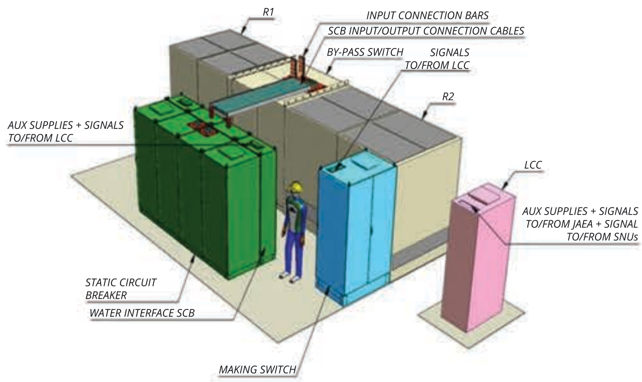


Case Study: Switching Network Units (20 kA, 5 kV) for the JT-60SA in Naka, Japan

OCEM Power Electronics' four switching network units (SNU) will help induce and sustain the loop voltage needed for plasma initiation in the JT-60SA.

The JT-60SA, or Japan Torus 60 Super Advanced, is a collaboration between the Japanese and European fusion research communities intended to complement the International Thermonuclear Experimental Reactor (ITER) under construction in Cadarache, France. Managed by the Japan Atomic Energy Agency at the Naka Fusion Institute, and governed by the "Broader Approach" agreement between Europe and Japan, the project will be an upgrade to the JT-60 fusion reactor built in 1985.

While the JT-60SA and ITER are independent research initiatives, JT-60SA was designed to support ITER's research aims by developing and testing practical and reliable plasma control schemes suitable for future power plants. When JT-60SA goes live in 2019, major research fields will include operation regime development, stability and control, transport and confinement, high-energy particle behavior, plasma material interaction, fusion engineering, and theoretical models and simulation codes.



SNU final configuration

OCEM Power Electronics was commissioned to produce four Switching Network Units, or SNUs, to induce and sustain the loop voltage needed for plasma initiation in the JT-60SA.

The Switching Network Unit

The JT-60SA employs the most advanced fusion reactor available today, called a "tokamak" — a Russian word for a torus, or doughnut-shaped, magnetic chamber. The plasma is confined in the chamber using a magnetic field generated by a toroidal field coil and heated until fusion occurs. A central solenoid coil provides the inductive flux to ramp up the plasma current and contribute to plasma shaping.

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SNU - Switching Network Units for the JT-60SA

A detail of Local Control Cubicle

The central solenoid coil in the JT-60SA is divided into four superconducting modules called CS 1-4. Each of the four superconducting modules is connected to an independent power supply circuit that includes a four-quadrant AC/DC converter and a SNU.

The SNUs are used to produce the high voltage required for the plasma initiation by exploiting the magnetic energy stored in the poloidal coils. This is accomplished by inserting resistors in the CS coils' circuits. When the main switch opens it puts the resistors in series to the coils, and as the current drops the voltage rises to create plasma.

Since the JT-60SA central solenoid is divided into four segments, the switch time needs to be extremely short to guarantee synchronization of the coils' rise in voltage. To achieve this, OCEM developed an innovative hybrid electromechanical-static switch configuration. The coil current has a nominal value of up to ± 20 kA and is sustained by both an electromechanical by-pass switch and a solid-state static circuit breaker switch. Due to the novelty of the system and the critical role the SNUs play in plasma initiation, the first SNU was subjected to rigorous testing before production began on the additional three systems. These tests proved highly successful.

SNU Production and Testing

OCEM was contracted by the Italian National Agency for New Technologies, Energy and Sustainable Development (ENEA) in October 2012 to produce the SNU systems. It completed the approved designs in July 2013, and the first full-scale, fully working prototype was then manufactured in 2013-14. The components of each SNU are enclosed in six cubicles containing an electromechanical by-pass switch with a super-capacitator auxiliary power system, grounding switch and selectors; an electronic static circuit breaker with water cooling system; an electronic make switch with water

Switching Network Unit

cooling system; and two breakdown resistor banks. A single Local Control Cubicle controls the four SNUs.

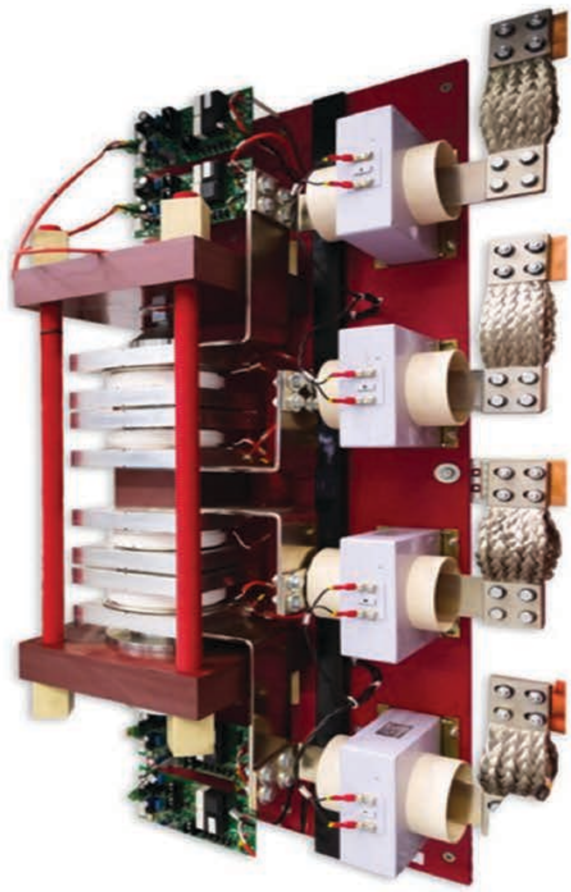
In September 2014, the system was tested inside a working Tokamak, the Frascati Tokamak Upgrade (FTU) at ENEA. OCEM and ENEA technicians assembled all the components with a layout identical to the final JT-60SA configuration, emulated the remote control system and synchronization method, and successfully tested the prototype SNU at nominal current and voltage.

Primary tests were repeated 10 times at reduced current and voltage values, with the operation of a single electronic static circuit breaker, to validate the correct operation and timing sequence of the current commutation from the electromechanical by-pass switch to the electronic static circuit breaker, and then from the electronic static circuit breaker to the first resistor. The current was then increased to the nominal value of 20 kA to simulate the SNU's complete operation sequence. Ten tests were conducted at 20 kA and 5 kV, with a repetition time shorter than the JT-60SA repetition time (1800 seconds) and without the water cooling available in the final installation. Different faults were simulated to confirm the SNU would take the proper protective action in each case.

The testing confirmed that the SNU performed to all specifications required by the JT-60SA, including an off-switch time significantly below the 1 ms threshold. Manufacturing of the remaining three SNUs was completed in 2015, and on-site tests were successfully conducted that fall.

Special Features

Each SNU must interrupt a direct current of up to 20 kA in less than 1 millisecond in order to produce a voltage of up to 5 kV. Since the central solenoid is segmented into four sections, it is critical that the intervention occur simultaneously in all four SNUs, meaning the maximum main switch opening and closing times must be less than 1 ms each. During on-site testing, the highly critical switch off-time was less than 0.1 ms, and the switch on-time was about 1 ms.



Thyristor Stack, a component of SNU

SNU - Switching Network Units for the JT-60SA

Components and Specifications

SNU Performance Characteristics	JT-60SA Specifications	Experimental
Nominal Current	+/- 20 kA	+/- 20 kA
SCB current interruption capability (safety margin)	25 kA	25 kA (3125 A per branch)
Rated voltage (across SNU terminals)	5 kV	5 kV
Maximum voltage (including overshoot and trabsients)	7 kV	5.2 kV
Maximum SNU operating time (including accuracy)	1.5 ms	80 us
Maximum MS closing time (including accuracy)	2 ms	140 us
Maximum SNU closing time (including accuracy)	1.5 ms	1.25 ms
Worst-case SNU operating time in non-nominal conditions	Not considered	700 us
MS closing time in worst-case non-nominal conditions	Not considered	40 us
SNU closing time in worst-case non-nominal conditions	Not considered	1 ms
Maximum BPS opening time (only for reference)	15 ms	15 ms
Maximun pulse lenght	250 s	> 250 s
Minumum repetition (cool-down) time	1800 s	< 1800 s
Voltage drop in SNU closed status	>10 V allowed	< 10 mV
Range of R1 resistance adjustable by selectors	0.25 ÷ 3.75 Ω	0.25 ÷ 3.75 Ω
SNU resistance after successful breakdown	Up to 22 mΩ	Up to 22 mΩ
Tolerance of each breakdown resistors (20°C)	+/- 2%	Better than +/- 1.5%
Maximum variation of resistors with temperature	10%	8%
Total energy that can be dissipated in breakdown resistors R1 and R2	90 MJ	>> 90 MJ
Temperature of air to environment	100°C	<< 60°C
Maximum current imbalance among parallel branches	20%	11%
Minimum cycles without compressed air	2	Unlimited
Self-protection time in any case of fault or alarm	Not specified	< 150 ms

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.

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