In parallel to the ITER project, European Union and Japan signed an agreement called “Broader Approach” for the realization of researches complementary to ITER with the aim to accelerate the development of nuclear fusion.

Broader Approach is a bilateral cooperation between Europe and Japan and comprises three major research projects.

1. The Satellite Tokamak Programme (STP), for the construction and operation of a big superconducting tokamak, satellite to ITER (JT-60SA).
2. IFMIF-EVEDA, which consists in the development and validation of IFMIF (International Fusion Material Facility) to test materials for a future fusion reactor, also through the realization and test of prototypes of key components.
3. The third project concerns the establishment of the research centre IFERC (International Fusion Energy Research Centre).

The European participation to the Broader Approach is mainly based on voluntary in-kind contributions of some countries, including Italy.

For the STP Project, Italy participates with the procurement of power supply systems for JT-60SA with very innovative characteristics. Their realisation has been committed by the Ministry of Education to CNR, which in turn asked Consorzio RFX to perform the design activities and the construction of the devices.
The JT-60SA project is the last frontier in the field of fusion research, resulting from the collaboration between European Union and Japan. JT-60SA is the satellite tokamak of the experimental reactor ITER, designed to contribute for a fast demonstration of the energy production from nuclear fusion.

In parallel to the construction of ITER, the first experimental reactor, which will have to demonstrate the scientific and technological feasibility of fusion energy, the realization of a new machine is foreseen, the JT-60SA tokamak design to test and develop alternative operative scenarios for the new fusion reactor.

For this project, as for the others foreseen in the framework of the cooperation between Europe and Japan (Broader Approach), Europe offered the voluntary contribution of some European Countries, including Italy, which undertakes to provide “in kind” high-tech equipment.

Once the project is realized, the European Countries, including Italy, will manage together to Japan the experimental activities on JT-60SA, following agreements under definition.
The JT-60SA (JT-60 Super Advanced) tokamak, designed in support and to complement the ITER operation, will be realized at Naka (Japan) using the existing infrastructures of a previous experimental devices called JT-60 Upgrade. The mission of JT-60SA is to contribute to the best result of the ITER experiments and to the design of the future prototype reactor (DEMO) by analysing and experimenting advanced plasma scenarios and by studying important physics and engineering issues.

JT-60SA will be equipped with superconducting magnets and will be able to confine very hot plasmas (with current up to 5.5 MegaAmps) for very long times (up to 100 seconds) thanks also to sophisticated additional heating systems; among all, the most advanced neutral beam injector ever built, able to accelerated particles up to 500 keV.

Being the most advanced tokamak before the ITER realization, important progresses toward fusion energy production are awaited from the experimental activity on JT-60SA.
The CNR contribution to the Broader Approach

To realize devices for the power supply systems of JT-60SA
Total investment 15 M€uro

In the framework of the Italian contribution to the JT-60SA project, CNR has been appointed by Ministry of Research for the procurement of two systems: the protection system for the superconducting magnets and the power supply system for the control of specific plasma instabilities.

CNR delegates Consorzio RFX of Padua for all the activities related with this commitment. The members of Consorzio RFX are CNR, INFN, ENEA, Padua University and Acciaierie Venete S.p.A.

Consorzio RFX has a long experience in the field of power supplies, gained on the RFX machine and increased on RFX-mod. The competencies of the lab allow, in addition to the procurement of the required systems, to participate to the following operation of JT-60SA, in the framework of the agreements presently under definition.

The commitment of CNR concerns the provision of two systems:

- Protection system for the magnets, which shall assure the fast discharge of the energy storage in the superconducting coils. It includes 13 units, presently already under installation on JT-60SA

- Power supply system for the control of specific plasma instabilities, called Resistive Wall Modes (RWM).
The protection circuits of the superconducting magnets

The function of the protection system for superconducting magnets is to rapidly discharge the energy stored on them in case of a severe fault called “quench”, which corresponds to the local loss of the superconductivity, with consequent overheating which can damage the coils.

These protection systems are based on switches, able to sustain the coil current continuously and, when necessary, to commutate it on resistors able to dissipate all the stored energy.

JT-60SA requires 13 protection units, called Quench Protection Circuits, three for the “toroidal” circuit and one for each of the 10 “poloidal” circuits.

The interruption of high currents is a complex operation; the technical solution proposed for JT-60SA has been developed on the basis of competences gained on similar systems both for RFX and for ITER and a specific research activity started in 2006.

Studies and experimental tests demonstrated the feasibility of the innovative proposed solution, based on an hybrid scheme composed by a mechanical breaker, able to sustain the full current with very low losses, in parallel to a static switch based on semiconductors, able to interrupt the current without producing arcs.

On top, the “toroidal” circuit of JT-60SA with the 3 protection units highlighted. The current to be interrupted is 25.7kA and the reapplied voltage is 2.8 kV

On the left, one of the 10 “poloidal” circuits of JT-60SA, with the protection unit highlighted. They will operate at 20kA / 4.2 kV
The contract for the procurement of the 13 protection units was awarded to Nidec ASI (former Ansaldo Sistemi Industriali) in December 2010; the firm adopted the reference design and developed the detail design approved in summer 2011.

Scheme of the protection unit for the poloidal circuit and CAD drawings of the main components: in blue the mechanical circuit breaker (ByPass Switch), in red the static switch (Static Breaker), in cyan the resistors (dump resistor) where the energy is discharged and in green the backup circuit breaker (pyrobreaker).

Mechanical circuit breakers, realized by Siemens AG, subsupplier of Nidec ASI for these components.

Static breakers, most innovative devices of this project, developed and realized by Nidec ASI S.p.A., supplier of the entire system.

“Pyrobreaker” realized by the Efremov laboratory of San Petersburg.

Resistors, realized by Telema S.p.A.

Cubicles containing the static breakers, at the end of the “routine” tests at Nidec ASI premises in Milan.
In the picture on the right, special tests on the new firing system of the “pyrobreaker”, the backup circuit breaker which has to interrupt the current in case of malfunctioning of the main circuit breaker.

On the bottom, “routine” tests on the mechanical breakers performed at Siemens premises.

The construction of the 13 protection units has started at beginning of 2013 and finished in July 2014.

The “routine” factory tests have been performed in parallel, as soon as the components where ready, under the supervision of Consorzio RFX.
Considering the high innovation level of the proposed solution, before realizing the 13 units, a full-scale prototype has been developed.

The prototype constituted the first realization of a hybrid circuit breaker rated for such current and voltage levels and the first example of application of this technology for protection systems for superconducting magnets.

**Qualification tests**

The special qualification tests of the two prototypes for the poloidal and toroidal circuits of JT-60SA have been performed at Consorzio RFX premises.

Two experimental campaigns of several weeks, during the shutdown periods of RFX-mod, in Springs and Summer 2012, allowed the complete characterization of their performances, with very positive results.
The factory tests and the qualification of the components of the 13 protection units have been completed in July 2014.

At the end of the realization phase and the factory tests, the components have been transferred to a facility where they have been prepared for the transoceanic transport and then wrapped with plastic, inserted in a special anti-humidity bag and anchored in a wooden box. The entire system has been packaged in 78 boxes, for a total weight of 137 tons.

On the left, the visit of the JT-60SA “Project Leader” in Milan in February 2014 to verify the progress in the realization of the 13 protection units.

The team, at the arrival of the wooden boxes at Naka.

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Arrival in Japan

Route of the ship which transported the devices to Naka, Japan

In the picture on the right, the protection system installed in one of the power supply halls of the JT-60SA experiment
Perfectly on time

The installation activities have been started at the end of November 2014 and finished in February 2015.
To control specific plasma instabilities called Resistive Wall Modes (RWM), 18 coils will be installed on JT-60SA, called "RWM control coils", placed on the plasma side of a conductive structure inside the vacuum vessel.

The National Research Council (CNR), through Consorzio RFX (Padova, Italy), is in charge to procure the power supplies for these coils. Besides the activity foreseen on the power supplies, Consorzio RFX contributes also to the development of the overall system, with specific analyses and physics studies which includes theoretical and experimental activities on RFX-mod, the machine of Consorzio RFX.
The power supply system has to satisfy very stringent requirements

The definition of such requirements for the power supply system for the effective control of the RWMs is the result of a long joint work between Consorzio RFX and the Naka Fusion Institute of the Japan Atomic Energy Agency (JAEA).

The stringent dynamic performance requirements were not satisfiable with a simple topology and standard components, so the Consorzio RFX has started the development of a prototype of the power amplifier, the heart of the power supply system, to verify the feasibility of the proposed scheme and availability of appropriate components at a reasonable cost.

Based on the results obtained it was possible to confirm the reference design and technical specifications and to prepare contract schemes (Procurement Arrangement) between F4E and JAEA and between F4E and CNR (Agreement of Collaboration), followed by the process of preparation of the tender for the delivery of the overall system that is expected to be completed during the year.

The development will include the phases of the design, realization and factory tests and the delivery of the system to the site, expected in 2018.

Nominal voltage 240 V
Nominal current 300 A
Current bandwidth 3 kHz
Maximum latency between reference and output voltage 50

The table summarizes the main requirements of the power amplifier, the hearth of the power supply system.

In the picture, the reference design of the system, developed by Consorzio RFX, which foresees a dedicated power amplifier for each of the 18 coils (in the red circle).

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Dummy load provided by the colleagues of JAEA to perform the qualification tests on the prototype; this load reproduces the impedance of the real coil up to 3 kHz. Another example of fruitful collaboration.
An international enterprise carried out by Europe and Japan.

The Italian agency involved is the CNR, which entrusted Consorzio RFX with the development of the activities in Padua, in the Research Area of the CNR.

The complex organizational structure for the design, construction and operational phases of JT-60SA has been defined in the international agreements.

On the bottom, the detail of the structure of the “EU Home Team”. In evidence, the CNR contribution.