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Realizzazione e collaudo dei sistemi per il controllo veloce del plasma di JT-60SA

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REALIZZAZIONE E COLLAUDO DEI SISTEMI PER IL CONTROLLO VELOCE DEL PLASMA DI JT-60SA

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Report Ricerca di Sistema Elettrico
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Obiettivo: A4
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Indice

Sommario

L'obiettivo A4 prevede la fornitura di otto alimentatori AC/DC non convenzionali e sei trasformatori MT/BT, destinati ad erogare le elevate correnti richieste da alcuni avvolgimenti superconduttori di JT-60SA. La fornitura include anche tutti i relativi interruttori, fusibili, protezioni, controllori, sistemi di raffreddamento, collegamenti di media e bassa tensione e quanto altro necessiti al loro funzionamento.

L'ENEA, dopo aver selezionato ed invitato diversi fornitori industriali europei, ha assegnato la fornitura di tutti i sistemi di alimentazione elettrica al Raggruppamento Temporaneo di Imprese (RTI) tra le ditte POSEICO e JEMA. Entrambe le ditte possono vantare una esperienza pluriennale nel campo dell'elettronica di potenza con competenze specifiche complementari nella componentistica e negli impianti per Fusione Nucleare.

Nel 2014 è stato approvato definitivamente da ENEA, F4E e JAEA il design dei trasformatori, mentre nel 2015 sono stati approvati definitivamente il design dei convertitori.

Il piano di realizzazione ha visto il completamento dei trasformatori per Fasta Plasma Position Control (FPPC) e il loro collaudo a settembre 2014, la realizzazione dei convertitori FPPC upper e lower si è completata a novembre 2014.
A febbraio 2015 i convertitori FPPC upper and lower furono collaudati con successo presso la sala prove della JEMA (Spagna). Per questi test due trasformatori già collaudati sono stati trasferiti in spagna per le prove di collaudo. Infine le prove sismiche del Crowbar (essendo un componente di sicurezza rilevante in Cl. B) sono state eseguite maggio 2015 in base alla norma IEC 60068-3-3 60068-2-47 presso il laboratorio esterno Virlab in Spagna. A completamento della sottofase 3b "la realizzazione di un prototipo di sistema Crowbar di un convertitore CS con relative prove" del contratto si prevede l'esecuzione dei test funzionali ed a piena corrente del crowbar per fine ottobre 2015. Questi test hanno avuto esito positivo. Inoltre, poiché tutta la documentazione fornita è in lingua inglese, i prossimi paragrafi sono riportati in inglese.

1 Introduction

JT-60SA is a Superconducting Tokamak in the framework of the "Broader Approach" (BA) Agreement between Europe and Japan, a program of complementary facilities to be realized in parallel to ITER and DEMO. In the framework of BA, the Italian National Agency for New Technology, Energy and Sustainable Economic Development (ENEA) has to provide eight Power Supplies (PSs) and six transformers for the JT-60SA, for supplying the Central Solenoid (CS1, CS2, CS3, CS4), the Equilibrium Field Coils (EF1 and EF6) and the Fast Plasma Position Control Coils (FPPCC). These systems are being procured by ENEA through a contract signed in August 2013 with Industrial Suppliers Poseico and Jema in Temporary Association of Enterprise.

The basic devices of the power supply for FPPCC consist in: a thyristor rectifier or base PS, a converter transformer, a crowbar (to protect by over-voltages and/or over-currents); whereas the load of the FPPCC is a magnet coil installed in vacuum vessel. FPPCC PSs have the function of controlling vertical position of the plasma against small plasma perturbation or a minor disruption, to prevent a Vertical Displacements Event (VDE) by two coils called upper and lower FPPC coils. The vertical stabilization requires that the FPPCC PSs have to be very fast in reacting to plasma movements, providing full voltage at any current level. For this reason, an open loop feed forward voltage control is adopted in order to achieve a fast control of FPPCC PSs. The characteristics of the PS are: 4-quadrant AC/DC converter 12-pulse, DC load voltage ±1000 V and DC load current ±5 kA.

The design of the FPPCC converters has been validated by a simulation model, finalizing the performances and dynamic behavior of voltage response. After the completion of the realization phase, the testing phase has been carried out in accordance to the IEC60146 Standards and this is the focus of the paper. The tests performed have pointed out a good dynamic behavior of the FPPCC converter in open loop feed forward voltage control, for a reference voltage step of 1kV, the rise time of output voltage is 2.88 ms, confirming outcomes achieved by simulations.

2 Description of activities

2.1 FPPCC PSs' realization and testing

Fast Plasma Position Control Coils (FPPCC) PSs have to be very fast for reacting to plasma movements, for this an open loop feed forward voltage control has been adopted in order to achieve a fast control of FPPCC PSs. The main characteristics of FPPCC base thyristor converter are: 4-quadrant AC/DC converter 12-pulse with circulating current, DC load voltage ±1000 V and DC load current ±5 kA. It is fed by 2 transformers to allow 12-pulses operations also during the circulating current phase. For further details on design choices for FPPCC PS's, whereas the characteristics are reported in Table 1.

The choice of FPPCC PS electric scheme based on thyristors (Figure 1) has been made to be fast, but also for a good cost/effectiveness trade-off, budget constraints, high robustness, great capability of overload, high reliability and expected plasma shape. The design phase was completed by Poseico and Jema in July 2014, the realization phase was finished in December 2014, and the testing phase was successfully completed, in February 2015.

The acceptance tests were performed at JEMA Laboratories in according to the IEC60146 Standards. According to the test procedure approved and the IEC Standard, acceptance tests were split in type and routine tests, among which:

- visual inspection;
- insulation test;
- pressure test;
- temperature rise test;
- functional test;
- noise test;
- full voltage and full current test.

All tests gave positive result, further the thermo-graphic camera did not highlight any critical hot spot. Figure 2 shows one of FPPCC PSs during the testing phase.

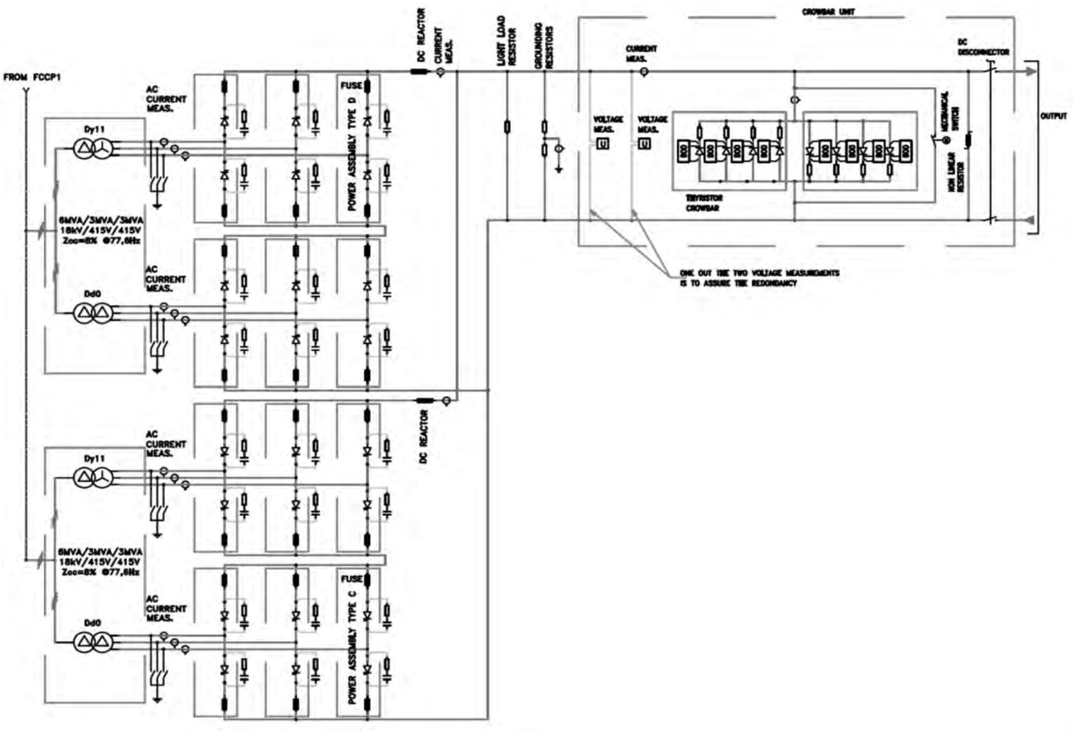

Figure 1 - The electric scheme of FPPCC PSs.

Table 1 - FPPCC PS Characteristics

CHARACTERISTICS	FPPCC PS
Units	2
Type	4 quadrants 12 pulses
DC Current	±5000 [A]
Load voltage	±1000 [V]
Control accuracy	± 1%
Duty Cycle	140/1800 [s/s]

Figure 2 - The view of a FPPCC PS in Jema Laboratories.

Type tests were performed to verify the load current and voltage rates (reported in Table 1) and the dynamic behavior of FPPCC PSs. The resistive-inductive load was made connecting in series ten DC reactors, achieving so a load of 7 mH and 24 mΩ, quite similar to the real FPPC Coils' ones (10.8 mH and 8.2 mΩ).
In the technical specification, both the current consign closed loop control and the voltage consign open loop control were required. For this reason type tests were split in current consign and voltage consign considering different reference signal steps both in current and in voltage. Also an additional type test was performed considering a step voltage signal reference at variable frequency from 1 Hz up to 50 Hz, in order to characterize the dynamic behavior of the output voltage of the FPPCC converter and its capability to follow fast variations of the plasma position. Among measure instruments for these tests an oscilloscope Tektronix MSO 4054 and various voltage and current probes were used to implement the measurement and acquisition equipment.
In this case the current control algorithm is closed loop. The regulation in the circulating current mode is active when load current is into the range [-500A, +500A] whereas outside of this range forward or reverse mode is active. Table 2 shows tests carried out and the voltage rise time measured.

Table 2 - Type tests for current consign

Type Test (Current consign closed loop control)				
Test N.	***Current consign***	***From***	***To***	***V Rise time [ms]***
1	Step	0	+5 kA	2.8
2	Step	+5 kA	-5 kA	3.6
3	Step	-5 kA	+5 kA	3.5
4	Step	+5 kA	0	2.9

Figures 3, 4 and 5 highlight the FPPCC PS dynamic behavior and in particular load (red line), forward bridges (blue line) and reverse bridges (green line) currents respectively; whereas in magenta dotted line is reported the DC voltage, during zero crossing of load current.

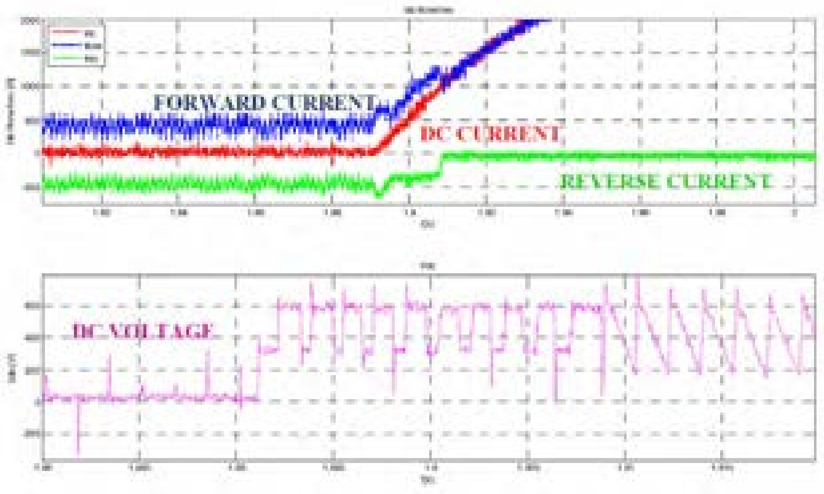

Figure 3 - Test number 1 for current consign

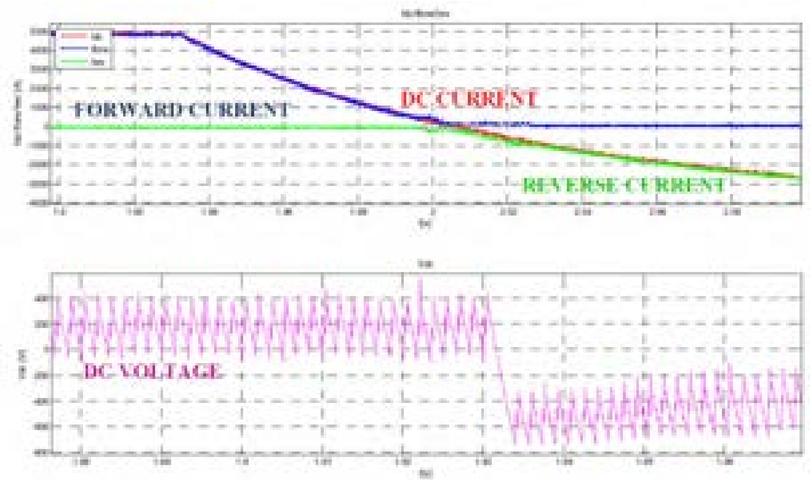

Figure 4 - Test number 2 for current consign

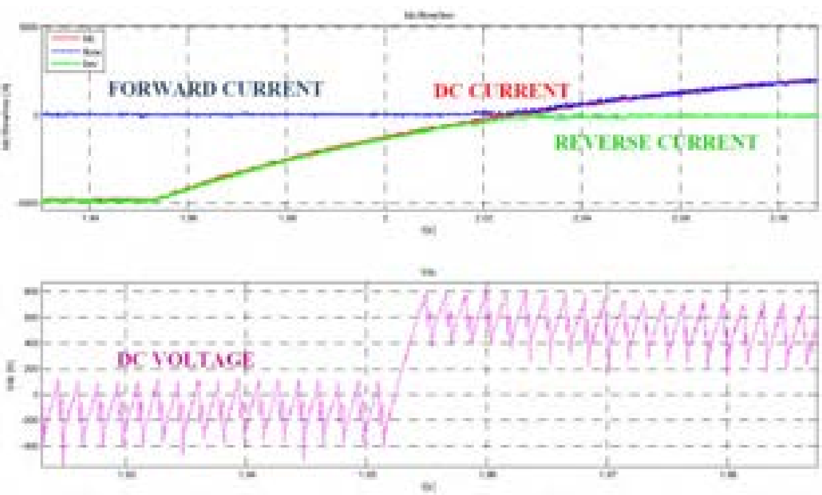

Figure 5 - Test number 3 for current consign.

Since this control algorithm is an open loop feed forward voltage control, a current limitation and a derivative firing-angle limitation were set up to ± 5 kA and 18000°/s respectively. Table 3 shows the outcomes of tests performed, whereas figures 6, 7, 8 and 9 point out the dynamic behavior of the FPPCC PS during testing phase.

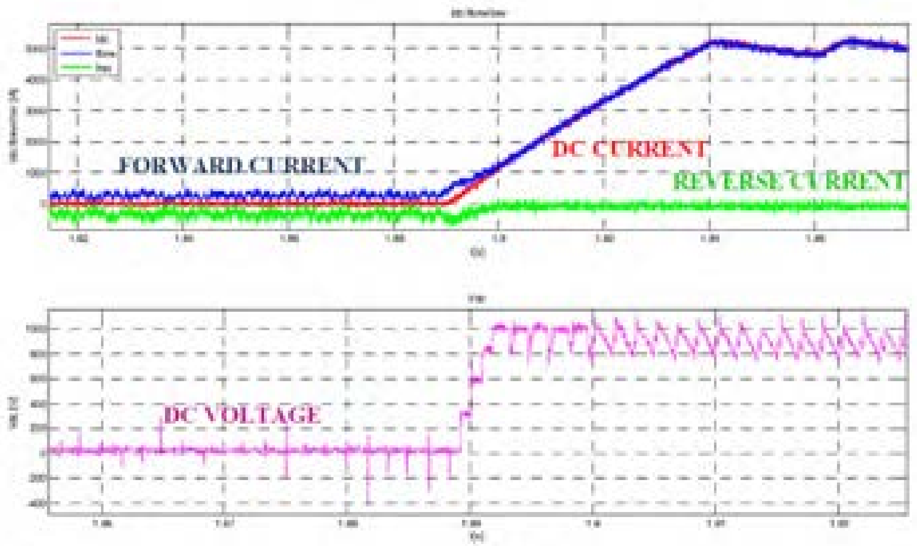

Figure 6 - Test number 1 for voltage consign.

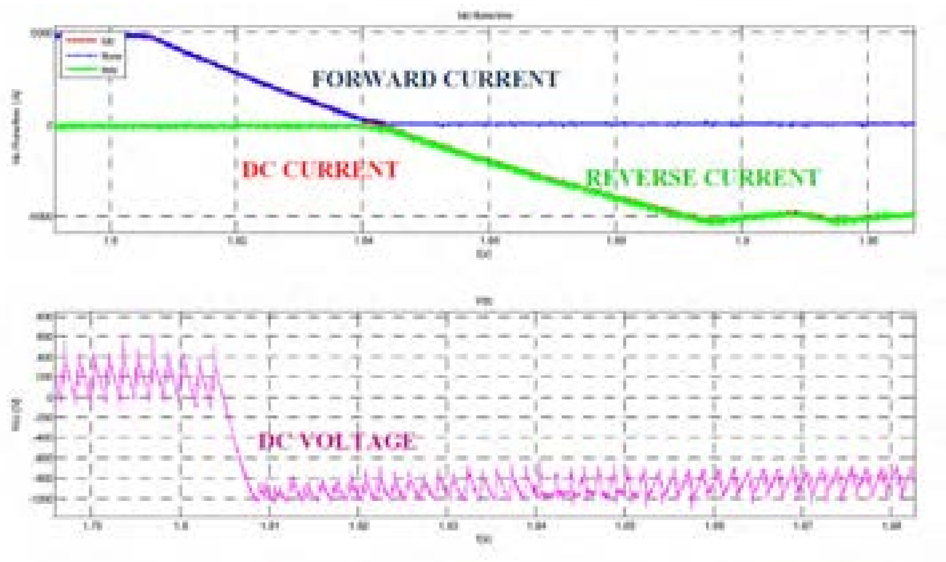

Figure 7 - Test number 2 for voltage consign.

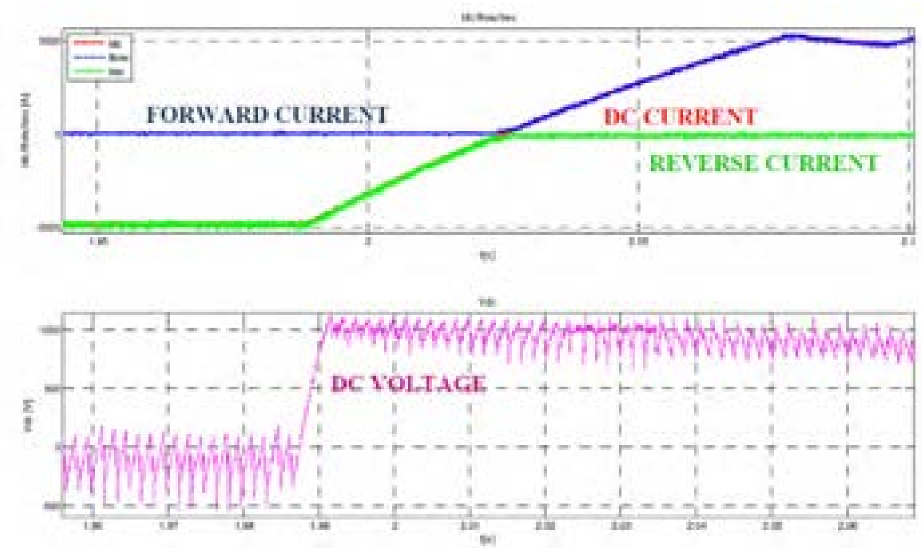

Figure 8 - Test number 3 for voltage consign.

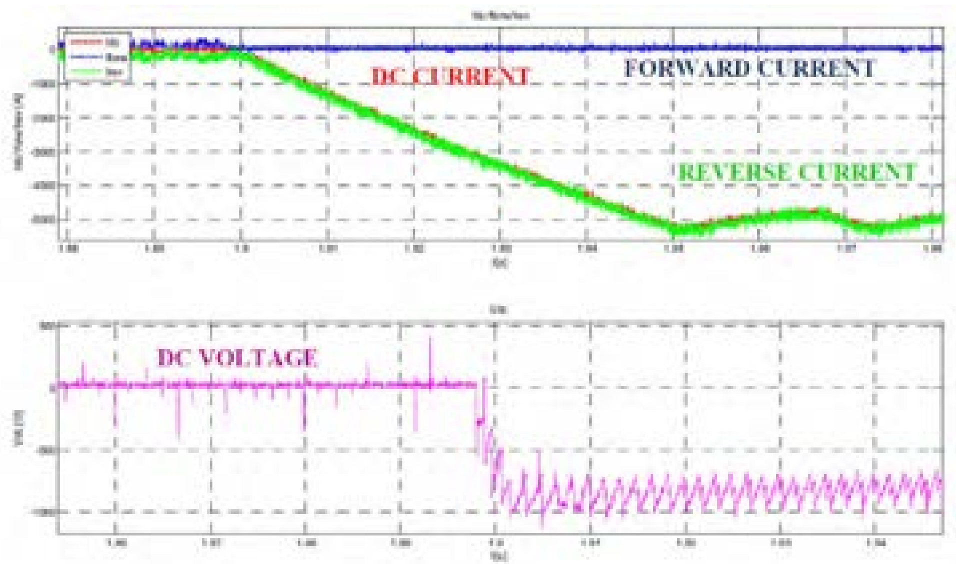

Figure 9 - Test number 4 for voltage consign.

Table 3 - Type tests for voltage consign

Type Test (Voltage consign open loop control)				
Test N.	***Voltage consign***	***From***	***To***	***V Rise time [ms]***
1	Step	0	+1 kV	2.9
2	Step	V_{dc} (+5 kA)	-1 kV	4.8
3	Step	- V_{dc} (-5 kA)	+1 kV	5.0
4	Step	0	-1 kV	3.7

Finally, an additional type test was performed considering a variable step voltage signal reference at variable frequency from 1 Hz up to 50 Hz and a duty cycle of 0.5, in order to characterize the dynamic behavior of the output voltage of the FPPCC converter and its capability to follow fast variations of the plasma position. Table 4 points out tests performed, taking into account for last two tests a circulating current of 1 kA.

Table 4 - Type tests with variable frequency

Type Test (Voltage consign open loop control)				
Test N.	*Voltage consign*	*Freq [Hz]*	*V_{DC} Magnitude [V]*	*I circ.-thresholds [A]*
1	Step	0.5	0, +100	±500
2	Step	2.5	0, +200	±500
3	Step	5	0, +200	±500
4	Step	25	0, +200	±500
5	Step	25	0, +600	±500
6	Step	25	0, +700	±500
7	Step	50	0, +100	±500
8	Step	50	0, +300	±500
9	Step	50	0, +300	±1000
10	Step	50	0, +1000	±1000

Figures 10, 11 12 and 13 show the dynamic behavior of FPPCC PS for voltage consign steps at variable frequency of 0.5 Hz, 5 Hz, 25 Hz and 50 Hz respectively, considering various magnitudes of the DC Voltage from 100 V up to 1kV.

The tests performed pointed out a good dynamic behavior of the FPPCC converter in open loop feed forward voltage control and a fairly good capability to follow fast variations of the plasma position.

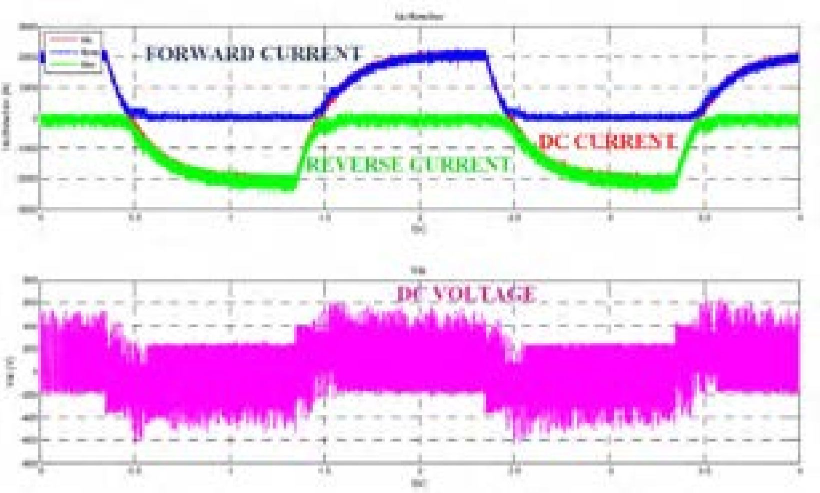

Figure 10 - Test number 1 for voltage consign at variable frequency.

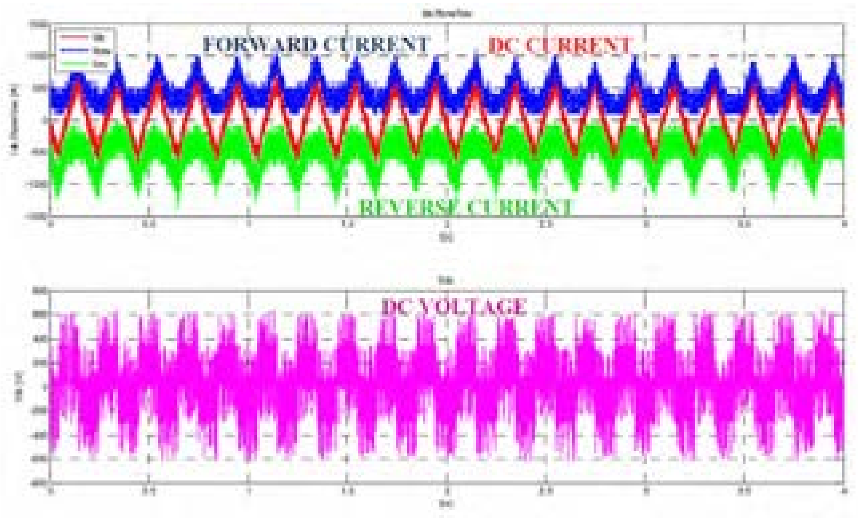

Figure 11 - Test number 3 for voltage consign at variable frequency.

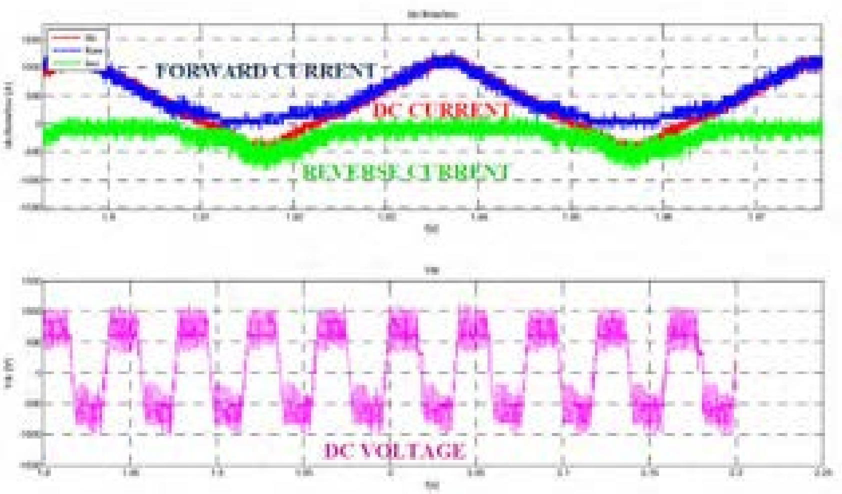

Figure 12 - Test number 6 for voltage consign at variable frequency.

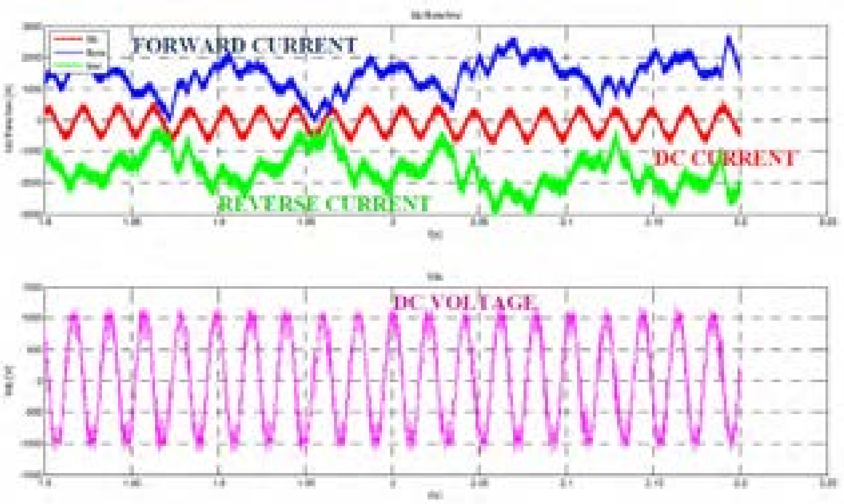

Figure 13 - Test number 10 for voltage consign at variable frequency.

Figure 14 – Seismic test of crowbar

The seismic testing of Crowbar (being a component of safety relevant Cl. B) were carried out in May 2015 in accordance with IEC 60068-3-3 60068-2-47 at the external laboratory Virlab in Spain. These tests were successfully carried out (Figure 14).

Conclusion

The acceptance tests were performed at JEMA Laboratories according to the IEC60146 Standards. All tests gave positive result. The tests performed pointed out a good dynamic behavior of the FPPCC converter in open loop feed forward voltage control, for a reference voltage step from 0 to 1kV, the rise time of output voltage was lower than 3 milliseconds, confirming outcomes achieved by simulations.

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