POWER SUPPLIES FOR MOLLER (INCLUDES PROTOTYPE, REFORMED PROTOTYPE AND PRODUCTION POWER SUPPLIES)

TECHNICAL PROPOSAL

dated NOVEMBER, 2021

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1. PROPOSAL OVERVIEW AND ADDITIONAL OPTIONS

This document describes the proposal for the magnet power supplies for the MOLLER project, located at Jefferson Laboratory (JLAB). OCEM, through its sister company Multi Electric located in Chicago, proposes all the needed power converters that will be designed and manufactured.

The proposed modular topology is derived by a ready-made and proven design of the Power Module used at TRIUMF, for the main cyclotron magnet, rated 20 kA 80 A. It used 16 modules in parallel connection, depicted here below:

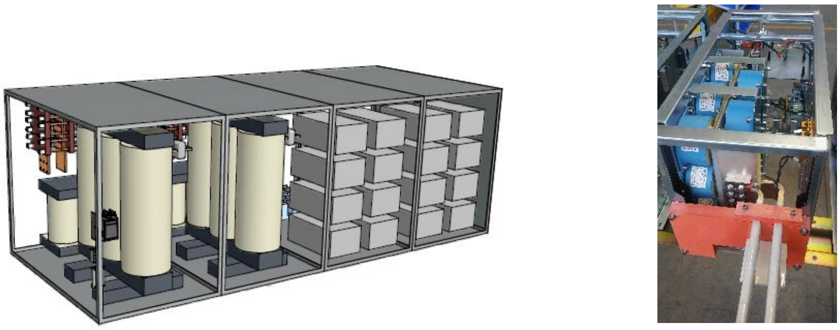


Figure 1 - General Layout and picture of the Power Module used in previous applications

Figure 2 – Example of a complete Power Supply (the picture is related to the TRIUMF Main Cyclotron magnet PS with 8 power modules visible in the front)

The main converter architecture, will be presented hereafter. Particular attention has been paid to the modularity and reliability of the converters as well as proposing a state-of-the-art solution with high-end technology as usually required for particle accelerator projects.

Using the same type of module for all the architectures (the optional power supplies use the same module) help to minimize the spare parts, decrease the MTTR (Mean Time To Repair) and maximize the continuous operation during the years.

The common part will be adapted to the power output level (input section, transformer, mechanical structure), while the number of modules and the modules themselves have been already designed with a proven reliability.

The individual power module (shown in **Figure 3**) is a water-cooled unit provided with IGBTs in the standard 150 x 62 x 17 mm package and completed with IGBT drivers, diagnostic board, bus-bar and local DC-bus film capacitors.

The use of film capacitors, gives also a strong contribution to the overall reliability of each module. Moreover, in case the module is used as a spare part and it is stocked for several years, it does not lose its electrical property during the stockage period.

The cooling plate of IGBT is realized with only copper and stainless steel in contact with water. The capacitors are sized to withstand the ripple current of the IGBT. The power module can be configured to realize different converter topologies and can be equipped with different IGBT and capacitors voltage ratings. For the application presented in this document, the module is configured as buck converter with three 650 V IGBTs modules in parallel and capable to deliver an output current of 1000 A at 10 kHz switching frequency. The main power components of the module are UL recognized. IGBT switching signals and status feedback signals are provided through optic fiber for improved disturbance immunity.

The following additional items are here for your consideration as options but have not been included in the Bid Schedule and price proposal:

- Dummy load, rental of a generator and autotransformer for tests at full power
- EMC and Safety certifications
- Motor Drive for reversal polarity of each power supply type

Qty	Additional Options	Type
1	Dummy load configurable + autotrafo 400->480 with taps + generator rental	
1	Motor drive for reversal polarity	**US torus**
1	Motor drive for reversal polarity	**DS Torus - 1**
1	Motor drive for reversal polarity	**DS Torus - 2**
1	Motor drive for reversal polarity	**DS-Torus 3**
1	Motor drive for reversal polarity	**DS Torus - 4**
1	EMC and Safety certifications	External Independent Lab

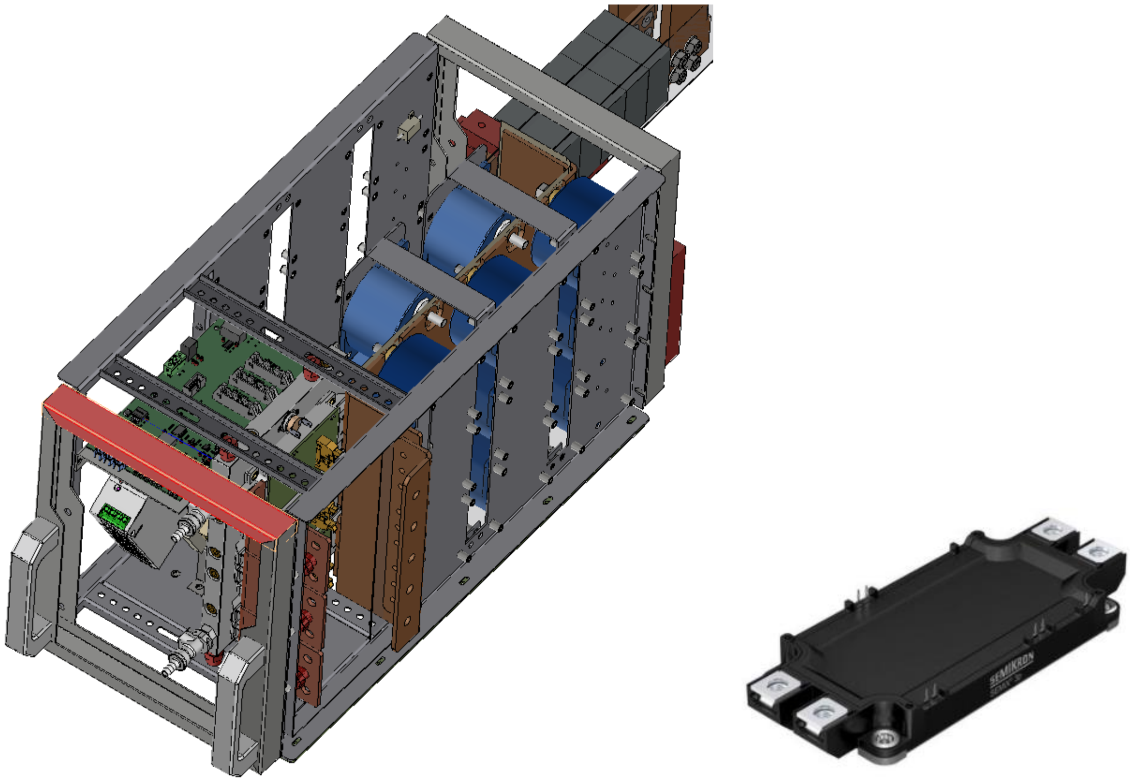


Figure 3 – Power module structure and adopted IGBT module format

This proposal will reference mainly, but not only, to the documents from JLAB hereafter listed:

[a] “*RFP JSA-22-R407215.pdf*”

[b] *“RFI -Source Sought.pdf”*

The first requirement is for a current regulated power supply operating over the range of 1075A to 3350A, used to energize water cooled copper coils to be employed in the Moller experiment. Total output current envelope of uncertainty/stability is ±25 parts per million (ppm). All the needed power supplies are hereafter listed in Table 1:

Power Supply name	Quantity
US torus	1
DS Torus - 1	1
DS Torus - 2	1
DS Torus - 3	1
DS Torus - 4	1

Table 1 – Required power supplies for the Moller project

Due to the size of the coils, a total number of 5 power converters will be needed, ranging from a minimum output power of 83 kW (US Torus) to a maximum of 750 kW (for the DS Torus C4).

The listed power converters are all used in DC, i.e. monopolar type.

The total number of power converters with their respective ratings are listed in the following **Table 2**. The ratings listed here includes the 120% of voltage margin stated in §1.0 and 120% of peak current capability stated in §4.2.1.iii. of the reference document [a]

Magnet Type/Name	Q.ty of Power Converters	Type	Peak Current [A]	Max. Voltage [V]	Rated Power [kW]
US Torus	1	Monopolar	1290	93	84
DS Torus - 1	1	Monopolar	2676	48	90
DS Torus - 2	1	Monopolar	2928	50.4	103
DS Torus - 3	1	Monopolar	3882	68.4	185
DS Torus - 4	1	Monopolar	4020	269	751

Table 2 – Power converters required

A total power P_{TOT} of approximately 1213 kW, or 1.3 MW, is needed for this part of the installation of the MOLLER power supplies at JLAB.

Water cooling will be applied on all the described power units.

The proposal will include all the power converters as well as the cabinets, Hardware interlocks (voltage, LCW flow, temperature) to allow integration into the personal safety system (PSS). The PSS interface to the system will be defined, per regulations, by the Safety System Group (SSG) means there will be a bi-annual certification of the system the Power Distribution Units (PDUs) where needed, the commissioning of the power units and everything needed (to be evaluated once the full information will be available).

The proposal includes all the testing as well as packaging, shipping and the testing on-site for two (2) senior engineers for 5 working days at JLAB.

A preliminary draft of the layout of the power converter unit is shown in **Figure 4** where the foreseen layout of the middle-size (DS Torus – 3) power converter cabinet is reported. The cabinet includes the main transformer that takes up most of the space and weight of the unit with foreseen dimensions 3000 mm (W) × 2200 mm (H) × 1200 mm (D) and a foreseen maximum weight of 2.500 kg; data that shall be confirmed after detailed design. Alternative mechanical solutions, like external transformer hosted into an IP 20 grilled cage, can be discussed and agreed during the detailed design. The largest unit (DS Torus – 4) will have higher size or the main transformer hosted into an external IP 20 grilled cage, but the cabinet composition will be similar.

One section of the cabinet (the rightmost shown in **Figure 4**) hosts the control system in a standard housing for 19 "rack control unit. The basic control unit provided with the converter, capable to fulfil all the control requirements, is contained into a 19” 3U crate shown in **Figure 5**. The control unit has a basic display and a multifunction pushbutton that can be used for local control and readout of working parameters of the converter.

The 19” housing of the cabinet can contain up to 37 rack units, so additional 32U spare space is available for fitting other equipment or panel indicators. As example and as option, not quoted in the proposal, a larger 15” touch panel operator can be fitted to improve the local management of the converter and to have a wider readout of the status and diagnostic.

Figure 4 – Preliminary draft of the power converter cabinet

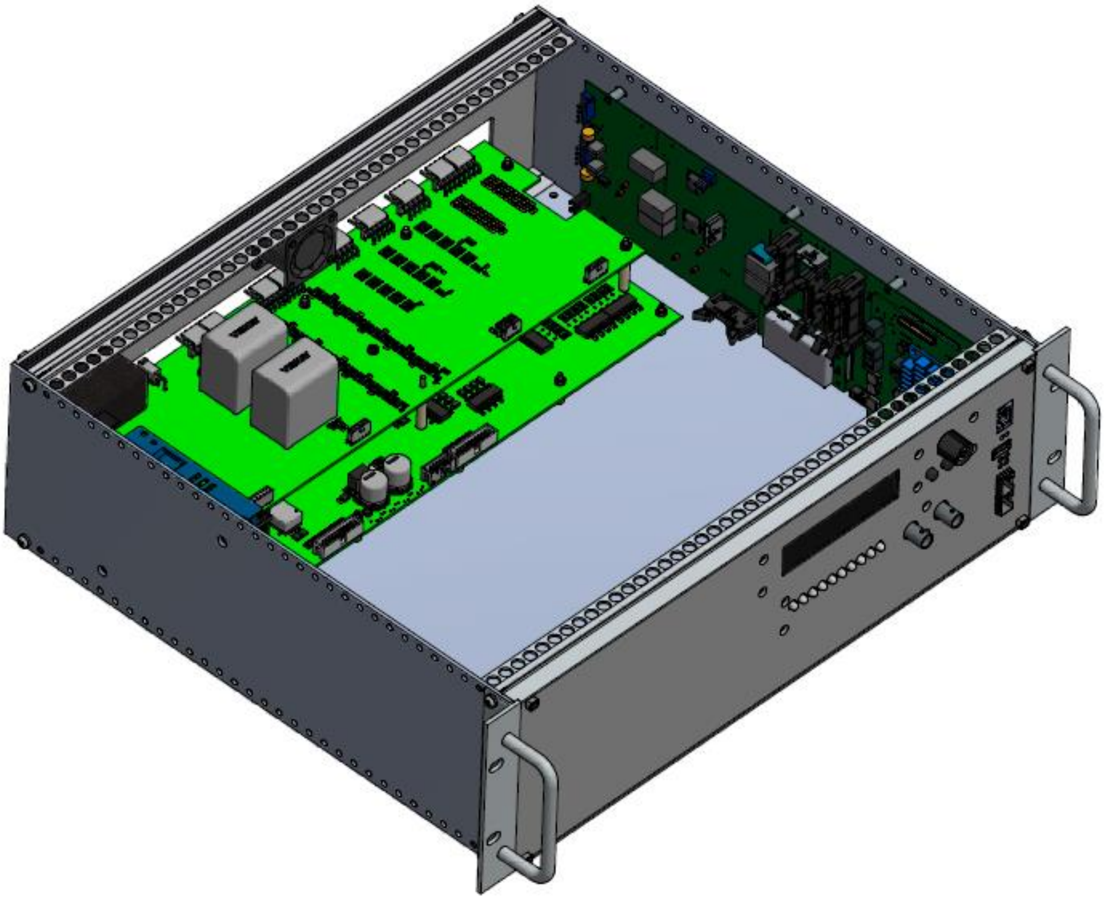


Figure 5 – Control crate with control boards (carrier + CPU module) and interface board

2. CABINETS AND INSTALLATION

A total number of five (5) cabinets is proposed for the entire installation as specified in the tender documents (1 prototype plus 4 optional units)

As requested by JLAB in the technical specification document **[a]**, the prototype will have the following functionality/features:

- A separate AC disconnect will be supplied by JLab for lockout and voltage verification unit (VVU). A separate enclosure with incoming AC-disconnect switch will be supplied with the power supply". System installations will have the Panduit or equivalent "Absence of voltage Tester";
- The disconnect switch will have its incoming terminals and contacts protected such that no incoming AC voltages are present inside the serviceable parts of the Power supply when the switch is in the "OFF" position;
- The disconnect switch will have an operator lever with provisions for padlocking "OFF" position (Lock-Out Tag-Out);
- Local / Remote control selection on the front side of the cabinets;
- Feet and lifting hooks installed;
- Contacts will be provided to interface with external safety circuitry. Contact opening to immediately inhibit the output current and the power supply to be commanded to STOP.
- External interlocks and Internal interlocks are provided - Thermal, overcurrent, overvoltage, e-stop, ground fault, phase imbalance, fault detect, Fusing, etc. ;
- This power supply is designed to operate continuously within the operating range for 24 hours per day, up to 7 days per week, per year during continuous operating for a minimum of 5 years;
- Requirements with ground fault detection for Jefferson Lab's intended applications, either the "+" or "-" output lead of the power supply may be referenced to chassis ground with an internal dedicated and configurable connection, the ground detector detects currents of both positive and negative polarity. Additionally, a circuit breaker is fitted on the ground connection to separate the output from ground in case of sudden increase of the ground leakage current of the load.
- Labeled with following information:
    - Grid connection power;
    - Maximum output voltage and current;
    - Required water flow and pressure;
    - Maximum operating temperature;

- Manufacturer name(s);
- Year of construction;

An Ethernet switch will be provided into the unit for the remote-control connection.
A maximum height of 2200 mm for the cabinets is proposed, with all the input/output electrical and hydraulic connections from the top.

2.1.1. Power Converter Architecture

The basic conceptual scheme of the converters, derived from simulation, is shown in the following ***Figure 6***. Some components aren't shown for simplicity, like the input circuit breaker.

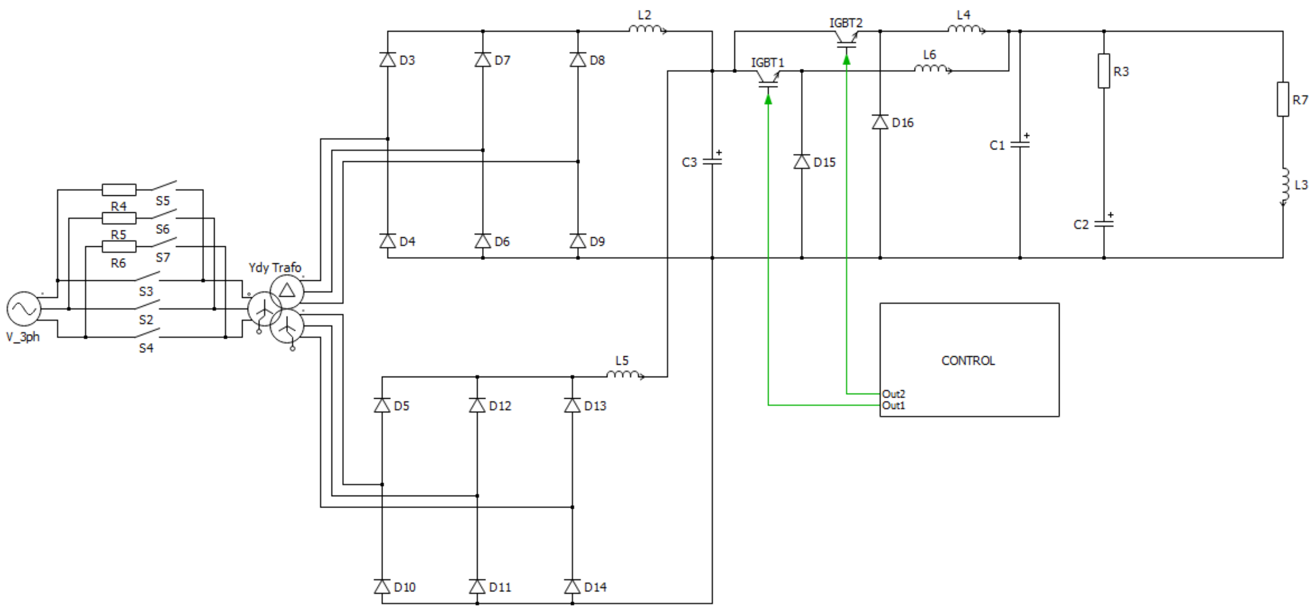


Figure 6 – Basic structure of power converters

The converters are based on a modular topology sharing the same basic conversion module across all the sizes.

The transformer and rectifiers generate a DC bus at first with "bulk" electrolytic capacitors (represented as C3 in the previous scheme) and they are sized to reduce the voltage ripple on the DC bus at the required level for assuring the stability ratings at the output.

The pre-charge circuit, performed before the transformer, is sized to assure a smooth inrush current either for the transformer and the rectifiers. Both the transformer and the diode bridge are sized to sustain the average output power. The peak power can be fed by the capacitor bank designed as C3.

The output H-bridges are composed of 650-V IGBTs which are more than sufficient for this application. The maximum DC-bus voltage (in the DS Torus – 4) will be 300 Vdc, and so a derating of factor of 2.1 with respect to the breakdown voltage of the power devices is assured.

2.1.2. Technical Specifications

Main technical specifications for these power converters dedicated to the JLAB are listed in **Table 3**:

Specifications	Value
Maximum Output Current	From 1290 A to 4020 A
Maximum Output Voltage	From 48 V to 269 V
Maximum Output Power	From 84 to 751 kW
Output Type	Unipolar
Output Control	Constant Current (CC)
Current and Voltage Setpoint Resolution	24 bit
Current and Voltage Readback Resolution	24 bit
AC Input Power	Input AC Voltage: 480VAC line-to-line 3-phase system, 3-wire including a safety ground. Input isolation and output power to be floating with a GND fault detection (safety)
AC Input Control Power	1-phase 120 VAC @ 50-60 Hz
Current Stability as defined in [a]	±25 ppm when operating at 90% rated current, after a 1 hour warm-up period
Voltage Ripple as defined in [a]	≤ 0.1% of output voltage

Current Reproducibility	< 25 ppm/FS	
Output Temperature Dependence	< 2 ppm/°C	
Efficiency	@FULL LOAD: @15 % load:	95 % 67 %
Cooling	Water	
Water Flow rate	< 120 l/min	
Inlet Temperature	< 32 °C	
Inlet pressure:	Min 125 psig, Max 160 psig	
Return pressure	Min 30 psig Max 50 psig	
Outlet temperature max	< 40 °C	
Remote Communication	10/100/1000 Mbit Ethernet	
Polling Rate	<= 1 kHz	
Embedded Features	Waveform Generation EPICS IOC Network Time Protocol (NTP) Real-time Oscilloscope	
Protections	Over-Voltage Over-Current AC and Phase Failure Over-Temperature Water Flow …	
Local Control	Yes - HMI (via Local Display and Navigation Switch) Emergency Stop Optional: 15” touch screen	
External Signals	Safety interlock, Standard Interlocks Status Signals (Solid State + Magnetic) Triggers	

Noise Level (at 1 meter)	< 80 dB(A)

Table 3 – main specifications of the power converter for the DS Torus

Regarding the power supply efficiency, it can be computed from main power components datasheets. In the case of full output power, the total power converter efficiency at full output power can be estimated as the total output power *Pout* divided by the sum of output Power, the conduction power losses *Pcond* and the switching power losses *Psw* :

$$\eta_{proto} = \frac{P_{OUT}}{(P_{OUT} + P_{COND} + P_{SW})} = 95{,}4\ \%$$

This is a theorical calculation with the assumption that the power converter would work at its maximum output ratings continuously and considering the foreseen worst-case specifications of the components. Real efficiency will be higher or equal to this result. During detailed design simulations with thermal model of the components will be performed to better define the efficiency estimate. Similar calculations have been made to estimate the efficiency at a 15% load level.

3. SIMULATIONS

The five configurations proposed have been simulated with the help of the software tool PLECS. The topology is the same for each configuration (and it is shown in Figure 1), with only the number of Triumf modules employed varying depending on the value of the output current of the configuration.

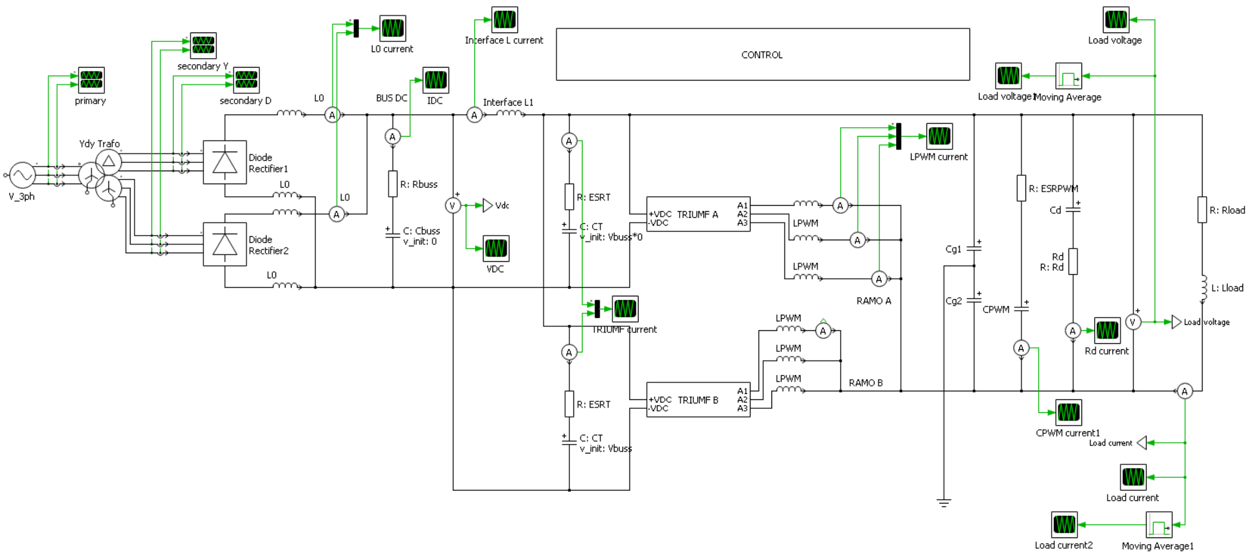


Figure 7 Electric scheme of US Torus configuration.

A transformer with two secondaries (with kVA rating that varies depending on the configuration simulated) has been used in order to exploit the advantages of the 12 pulses technique, then the current coming from the secondaries it is filtered and sent to the Triumf modules connected in parallel; then the output coming from the Triumf modules is further filtered through LPWM and CPWM (with a damping RC branch in parallel to CPWM).

3.1. Control

The control implemented in sumulation (shown in Figure 2) is a closed loop current control with the set point on the load current. The actual value of the load current is compared to a reference value and the resulting error is sent in input to a PI regulator; the PI output is compared to a triangular carrier having amplitude 1 and frequency 10 kHz, from this comparison a signal is generated, and (along with its negated) is used to drive the Triumf modules (that are driven all with the same signals). This simplified control is used to obtain working simulations, the actual digital control system implemented in the Power Supply controller is more sophisticated, with two nested regulation control loops and DC-bus ripple suppression algorithm.

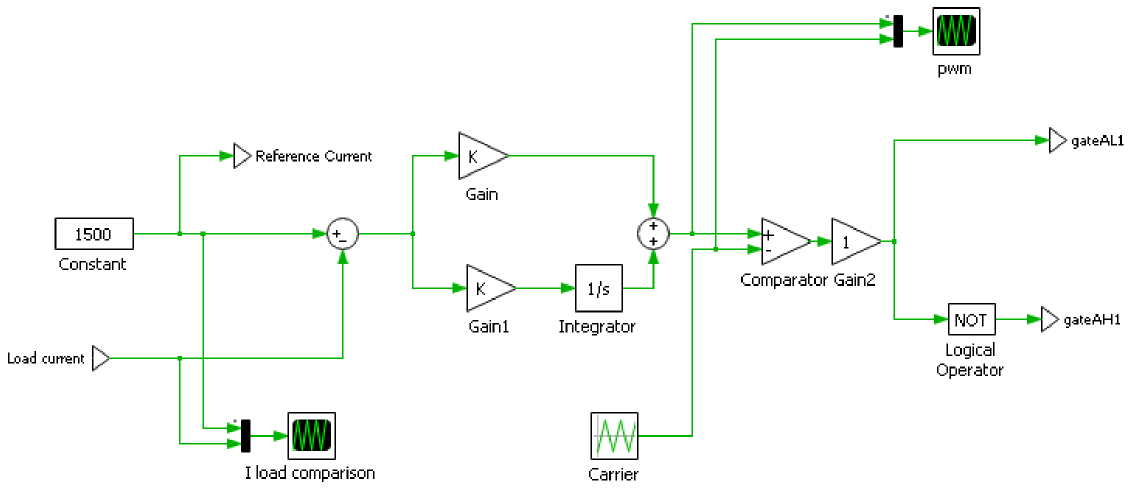


Figure 8 Control logic scheme.

All the configurations have been simulated at the 120% of the nominal current. In the following chapter, the main outcomes of each configuration will be shown.

3.2. Outcomes

3.2.1. DS Torus C3

The first configuration simulated has the characteristics summarized in the following table

Quantity	Value
Rated current	3235 [A]
Rated voltage	57 [V]
Load (resistive part)	0.013 [Ω]
Load (inductive part)	0.348 [mH]

In the next figures, the main outcomes of this simulation are plotted; the first picture, Figure 3, shows voltage and current waveforms on the load, over a time lapse of 5 s. Figure 4 is a zoom on the load current at steady state that shows the current ripple, as it can be seen, in this case, the precision is better than 25 ppm. Figure 5 shows what happens if the Triumf modules are suddenly shut down, the load current drops to 0 with the intrinsic exponential of the magnet, that is faster than 100 Ampere per second, as requested.

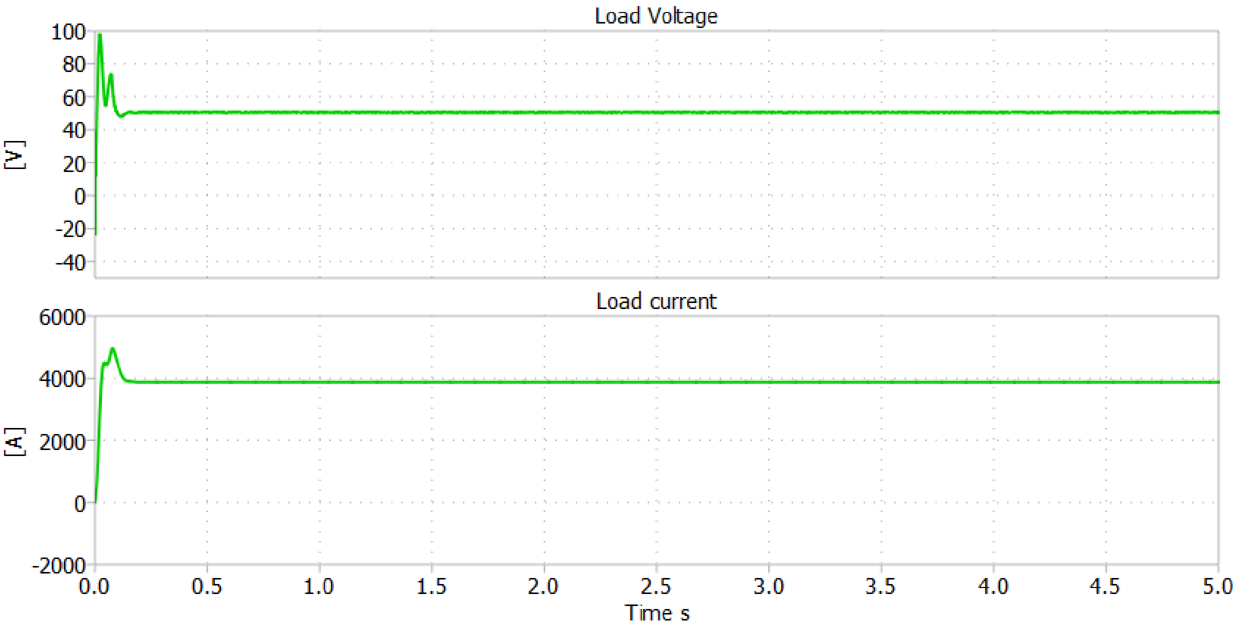


Figure 9 Load voltage and load current for the DS Torus C3 configuration.

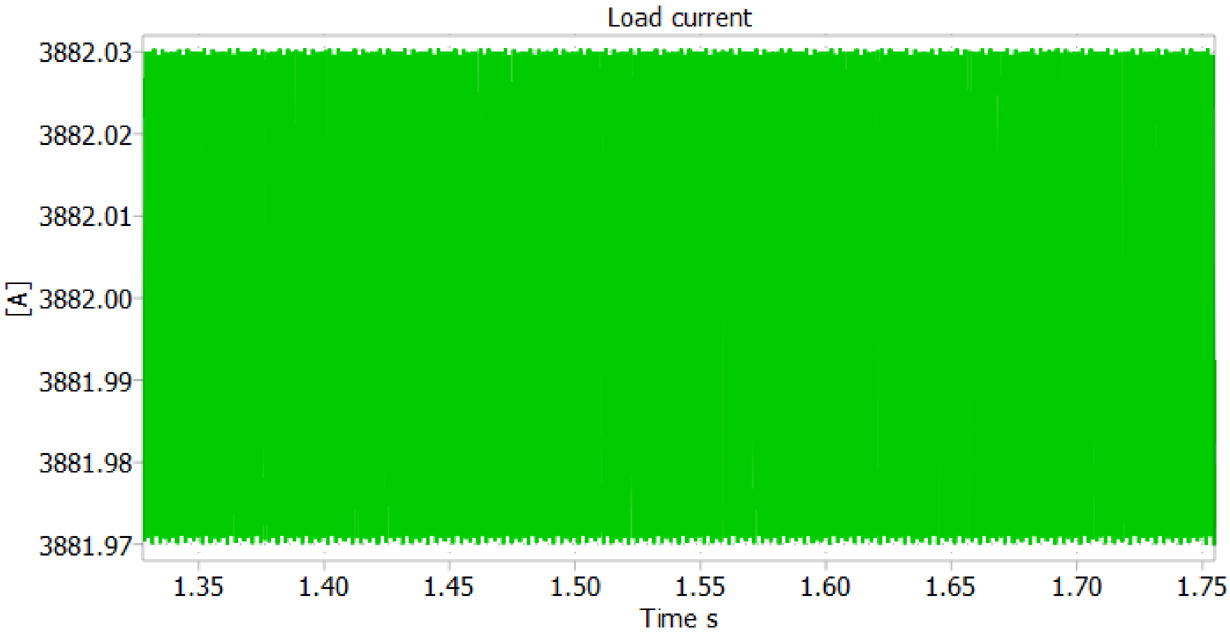


Figure 10 Ripple on load current at steady state for the DS Torus C3 configuration.

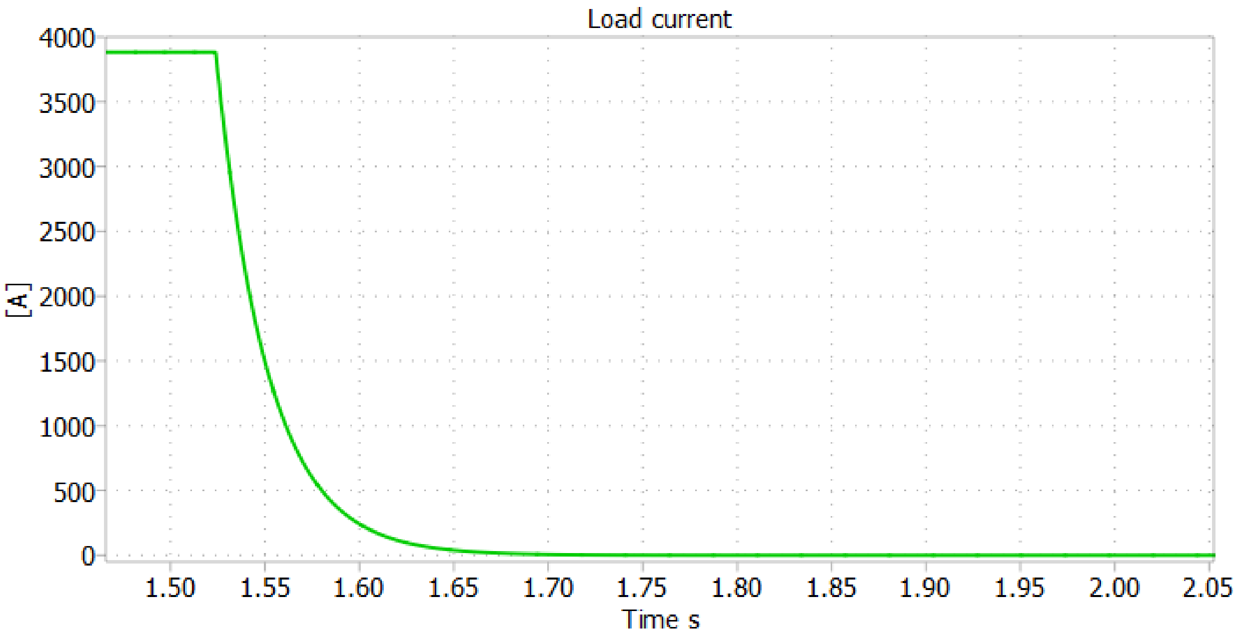


Figure 11 Load current decrease following the intrinsic exponential curve for the DS Torus C3 configuration.

3.2.2. US Torus

The second configuration simulated has the characteristics summarised in the following table

Quantity	Value
Rated current	1075 [A]
Rated voltage	77.5 [V]
Load (resistive part)	0.059 [Ω]
Load (inductive part)	0.631 [mH]

In the next figures, the main outcomes of this simulation are plotted; the first picture, Figure 6, shows voltage and current waveforms on the load, over a time lapse of 5 s. Figure 7 is a zoom on the load current at steady state that shows the current ripple, as it can be seen, in this case, the precision is better than 25 ppm. Figure 8 shows what happens if the Triumf modules are suddenly shut down, the load current drops to 0 with the intrinsic exponential of the magnet, that is faster than 100 Ampere per second, as requested.

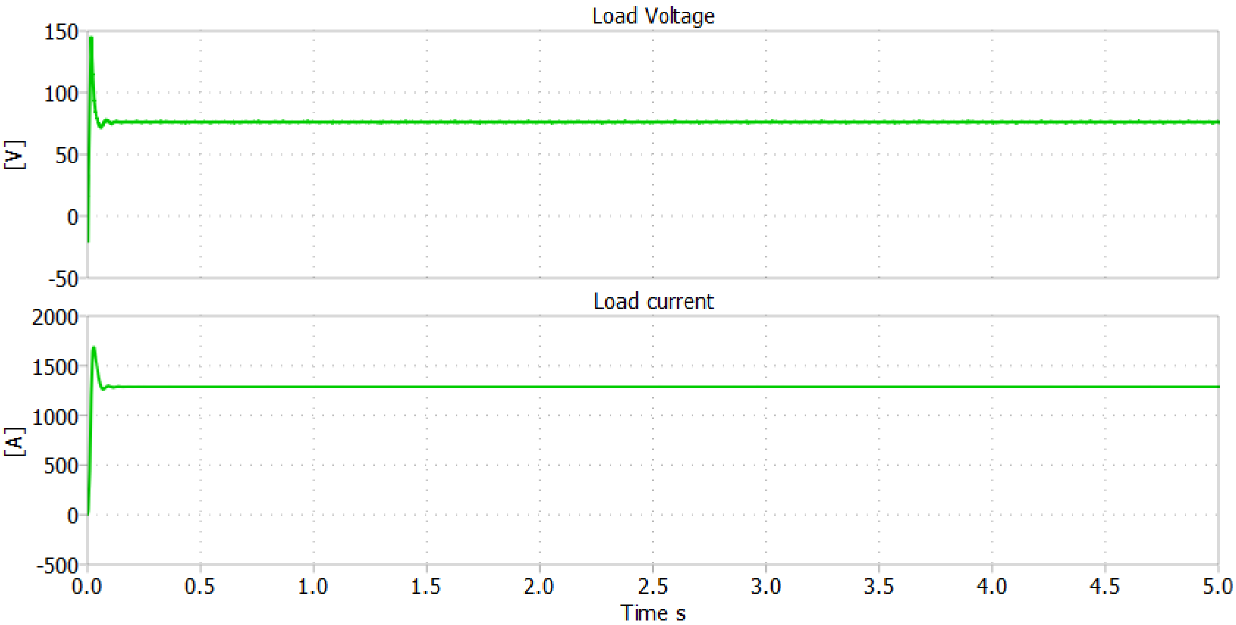


Figure 12 Load voltage and load current for the US Torus configuration.

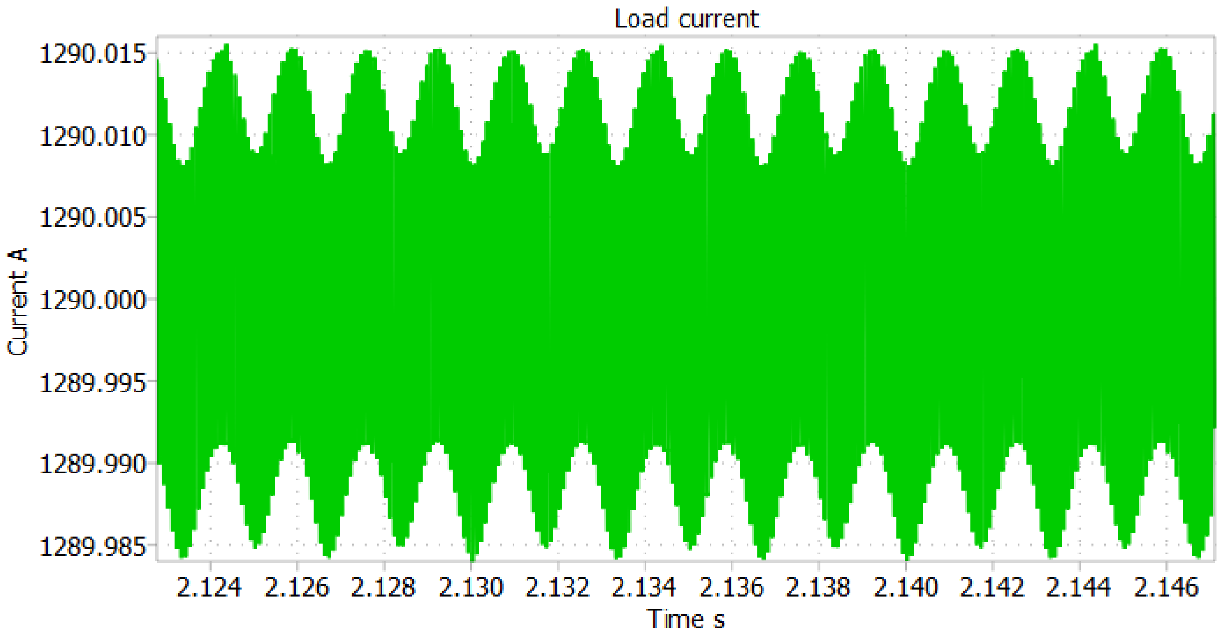


Figure 13 Ripple on load current at steady state for the US Torus configuration.

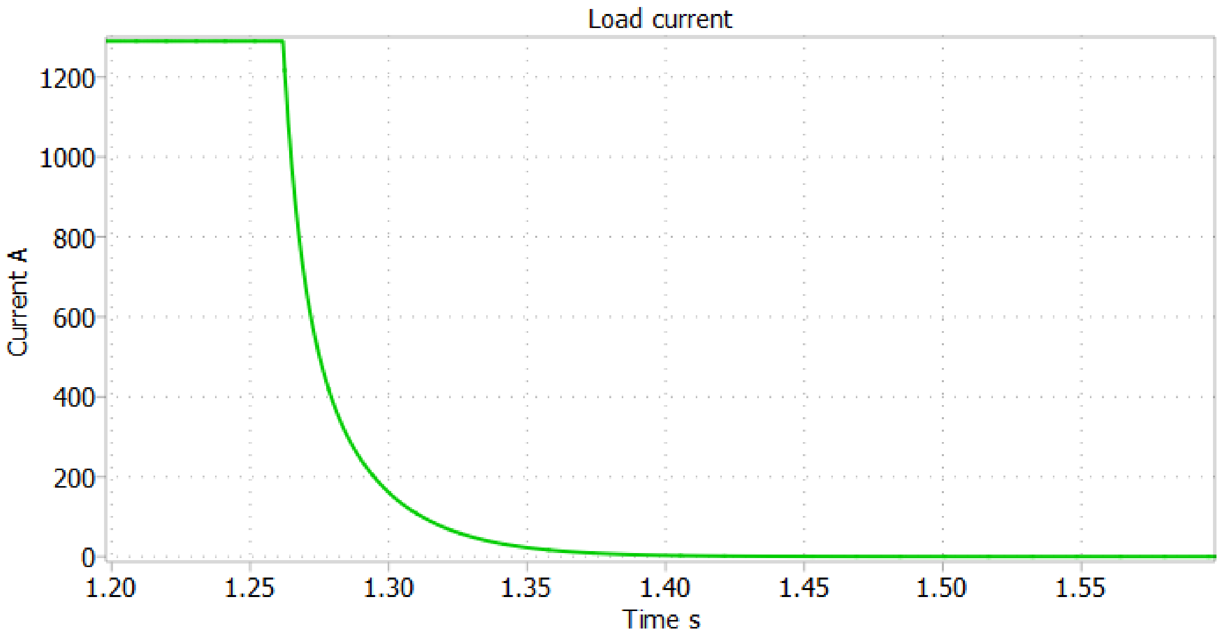


Figure 14 Load current decrease following the intrinsic exponential curve for the US Torus configuration.

3.2.3. DS Torus C1

The third configuration simulated has the characteristics summarised in the following table.

Quantity	Value
Rated current	2230 [A]
Rated voltage	40 [V]
Load 1 (resistive part)	0.015 [Ω]
Load 1 (inductive part)	0.153 [mH]

In the next figures, the main outcomes of this simulation are plotted; the first picture, Figure 9, shows voltage and current waveforms on the load, over a time lapse of 5 s. Figure 10 is a zoom on the load current at steady state that shows the current ripple, as it can be seen, in this case, the precision is better than 25 ppm. Figure 11 shows what happens if the Triumf modules are suddenly shut down, the load current drops to 0 with the intrinsic exponential of the magnet, that is faster than 100 Ampere per second, as requested.

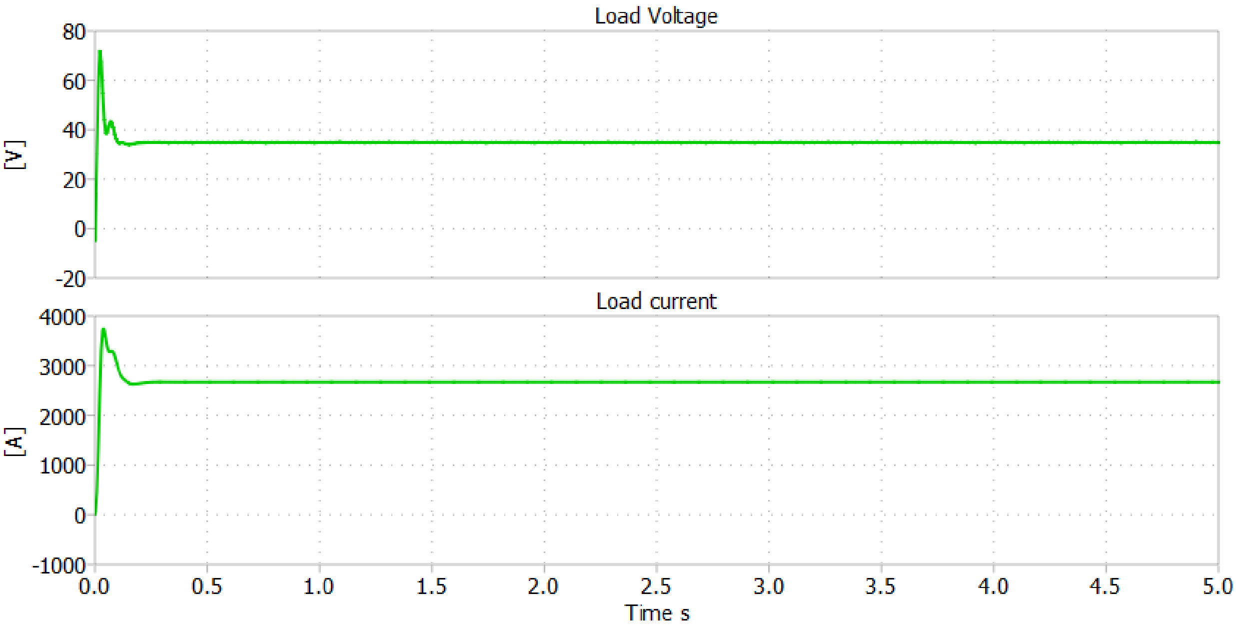


Figure 15 Load voltage and load current for the DS Torus C1 configuration.

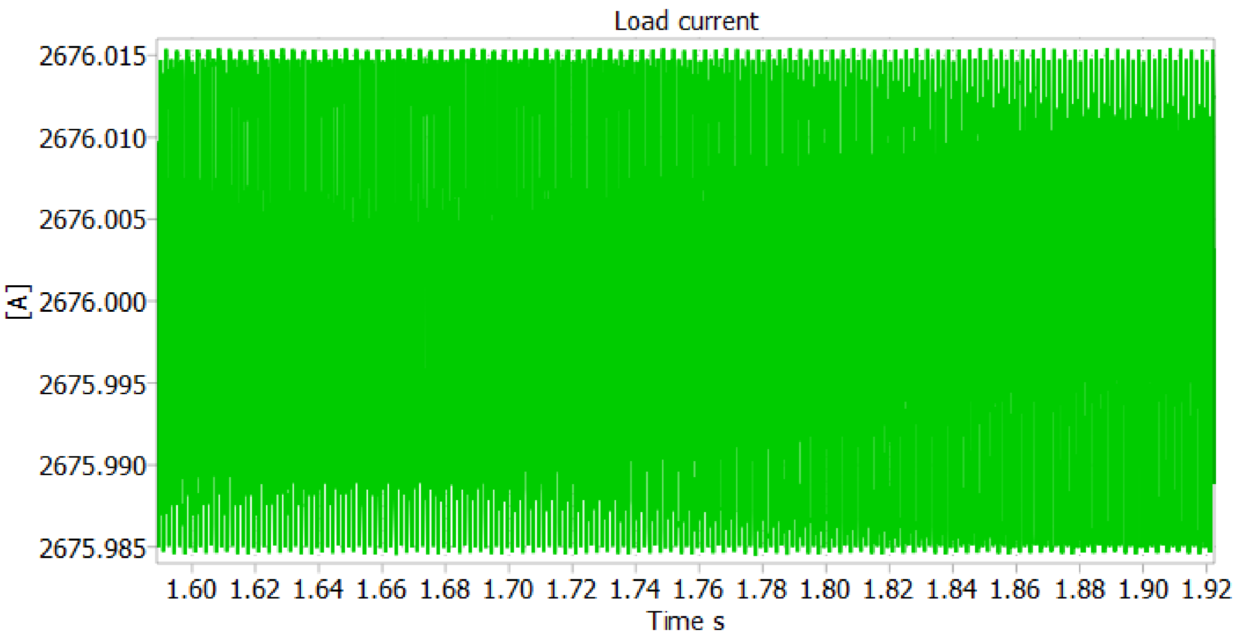


Figure 16 Ripple on load current at steady state for the DS Torus C1 configuration.

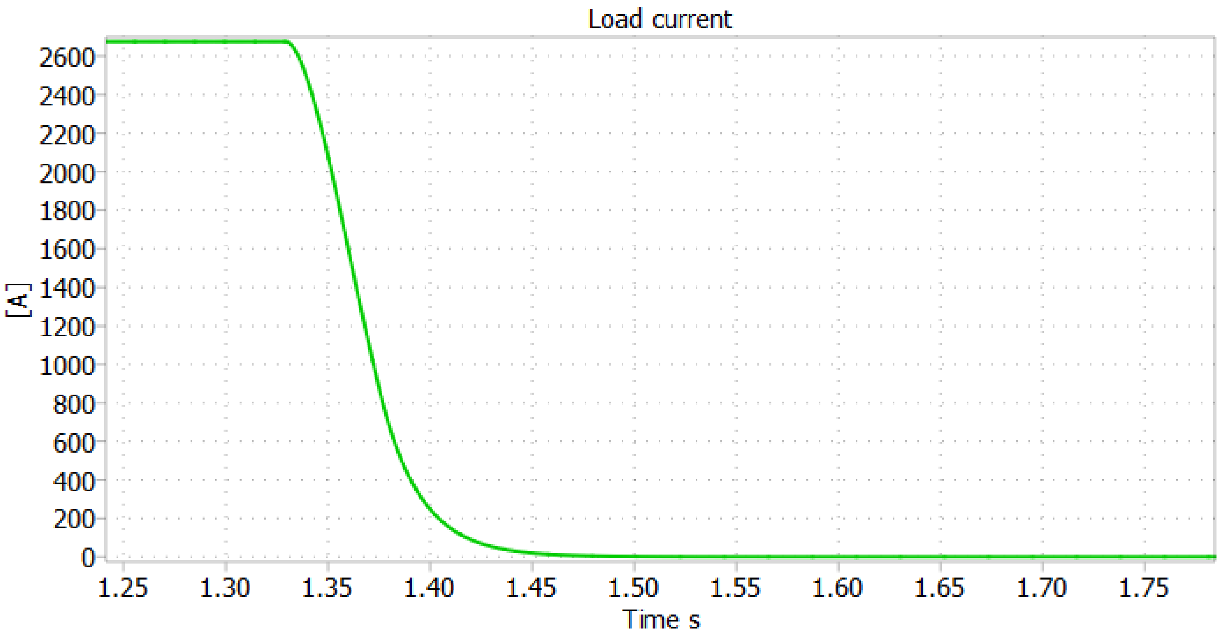


Figure 17 Load current decrease following the intrinsic exponential curve for the DS Torus C1 configuration.

3.2.4. DS Torus C2

The fourth configuration that has been simulated has the characteristics summarised in the following table.

Quantity	Value
Rated current	2440 [A]
Rated voltage	42 [V]
Load (resistive part)	0.013 [Ω]
Load (inductive part)	0.246 [mH]

In the next figures, the main outcomes of this simulation are plotted; the first picture, Figure 12, shows voltage and current waveforms on the load, over a time lapse of 5 s. Figure 13 is a zoom on the load current at steady state that shows the current ripple, as it can be seen, in this case, the precision is better than 25 ppm. Figure 14 shows what happens if the Triumf modules are suddenly shut down, the load current drops to 0 with the intrinsic exponential of the magnet, that is faster than 100 Ampere per second, as requested.

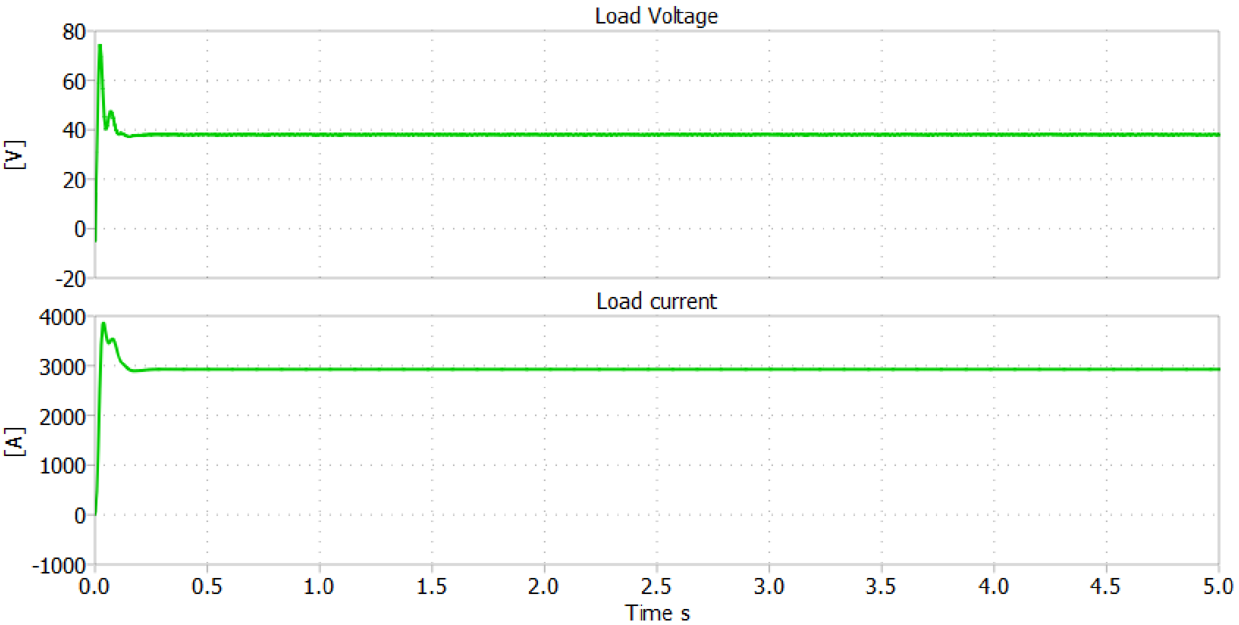


Figure 18 Load voltage and load current for the DS Torus C2 configuration.

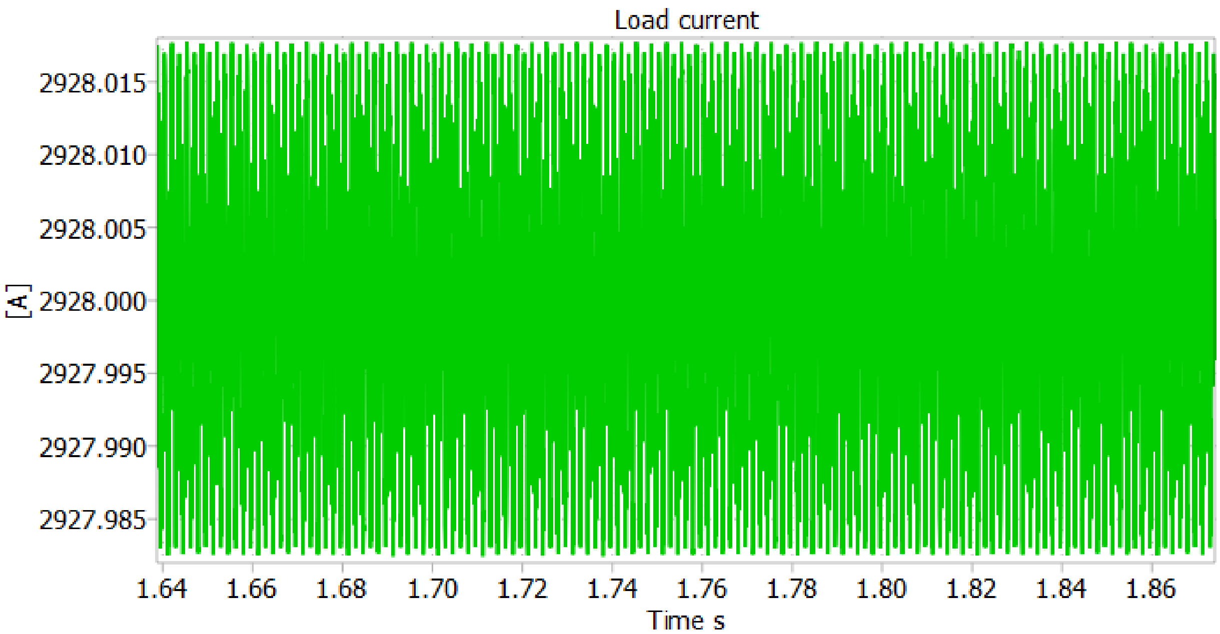


Figure 19 Ripple on load current at steady state for the DS Torus C2 configuration.

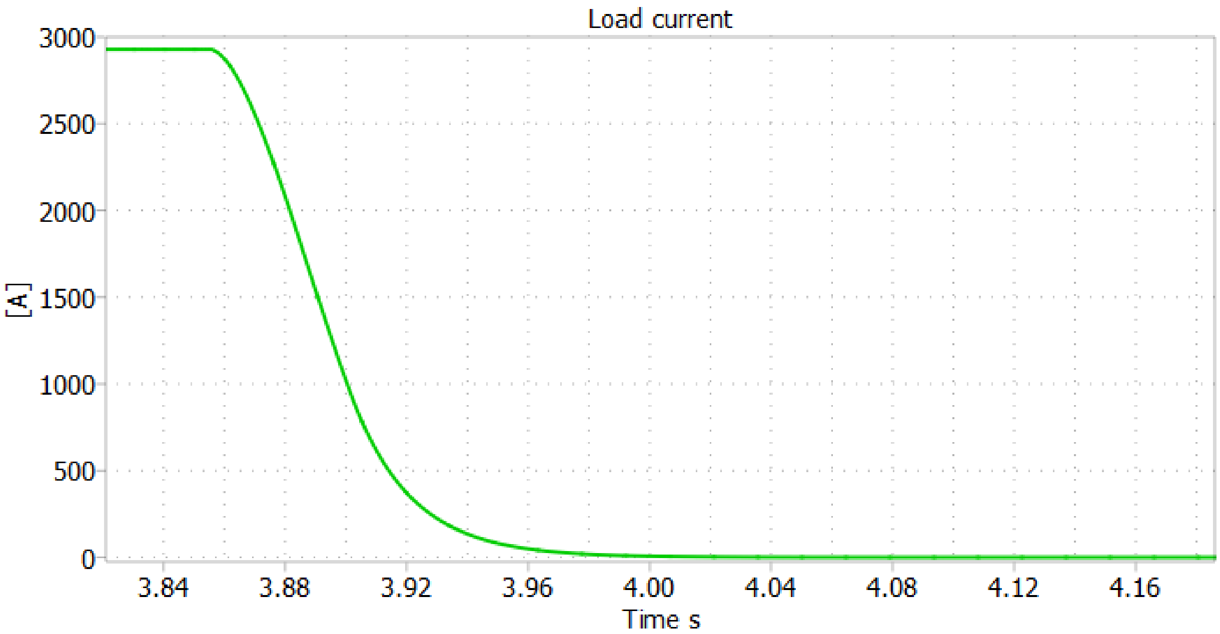


Figure 20 Load current decrease following the intrinsic exponential curve for the DS Torus C2 configuration.

3.2.5. DS Torus C4

The fifth configuration that has been simulated has the characteristics summarised in the following table.

Quantity	Value
Rated current	3350 [A]
Rated voltage	224 [V]
Load (resistive part)	0.056 [Ω]
Load (inductive part)	3.051 [mH]

In the next figures, the main outcomes of this simulation are plotted; the first picture, Figure 15, shows voltage and current waveforms on the load, over a time lapse of 5 s. Figure 16 is a zoom on the load current at steady state that shows the current ripple, as it can be seen, in this case, the precision is better than 25 ppm. Figure 17 shows what happens if the Triumf modules are suddenly shut down, the load current drops to 0 with the intrinsic exponential of the magnet, that is faster than 100 Ampere per second, as requested.

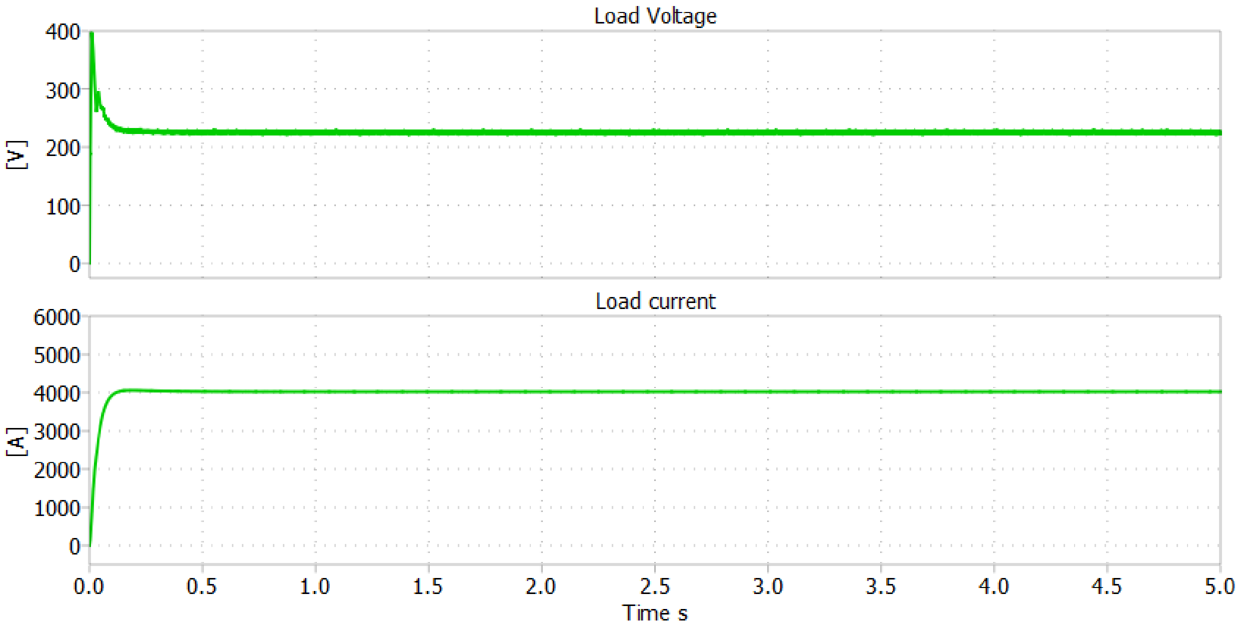


Figure 21 Load voltage and load current for the DS Torus C4 configuration.

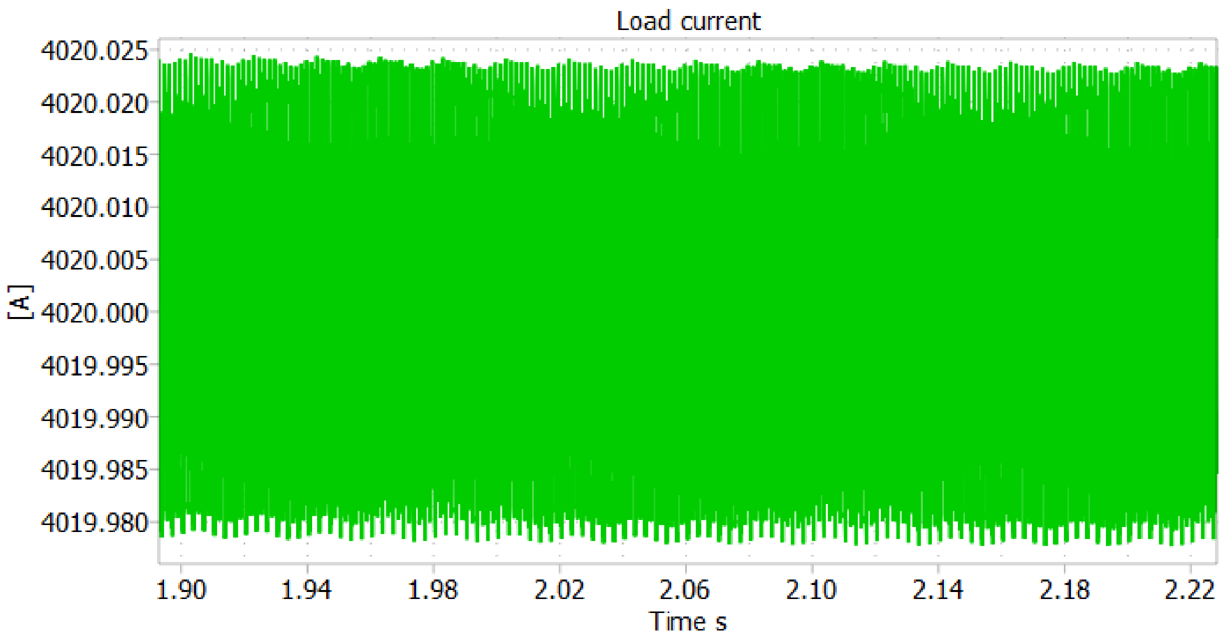


Figure 22 Ripple on load current at steady state for the DS Torus C4 configuration.

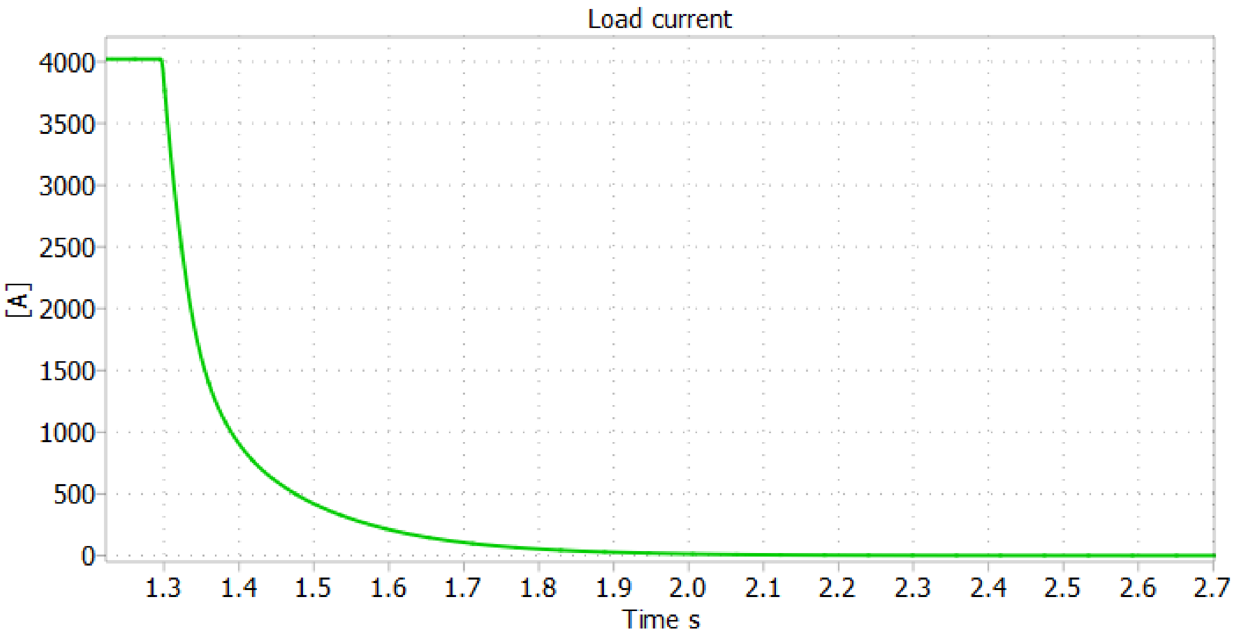


Figure 23 Load current decrease following the intrinsic exponential curve for the DS Torus C4 configuration.

3.3. Conclusions

All the five configurations have been successfully simulated. They are able to reach the rated operating point, they all satisfy the requirements about load current ripple at steady state (precision higher than ±25 ppm) and they all might be controlled with a current ramp between 100 A/s and 10 A/s since the intrinsic exponential current drop of the load is much faster. Starting from the parameters used to accomplish these simulations, the real elements to be bought on the market have been sized.

4. COMMON FEATURES OF THE PROPOSED POWER CONVERTERS

Many features are common for the proposed modules as they share the same control board, the same communication protocol and common software as well as the feedback sensing provided via 0-FLUCS Technology (with the DCCT option that is included in the FAST-PS in this proposal).

The control electronics has been developed thanks to the collaboration with the company CAENels, whose company share with OCEM Power Electronics the co-development of the NGPS small power supplies, a successful line of power supplies that is now extended to higher sizes like the one presented in this proposal.

The embedded Linux OS and Web Server basically allows the user to have unthought possibilities of developing his/her own software applications and routines directly INTO the power unit, thus becoming independent from any external platform and making the power supplies as “smart” and “intelligent” units as opposed to standard “simple” devices. This creates the opportunities for future developments and unpredicted needs that may arise even at a later time at an installation.

The EPICS drivers are available on-board directly on the power supply.

The VISUAL PS software also integrates a feature that allows accessing the EPICS IOC directly from there (more information in the attached “Remote Control Manual”).

EPICS IOC ***Linux OS Embedded***

Many other features are available and included in the offer as for example the possibility of running pre-defined **waveforms** or to load user-defined ones and to run them both in current or voltage mode.

The **Waveform Generator** functionality allows launching sine, square and triangular waves in both current and voltage mode by defining some simple parameters (offset, amplitudes, duty cycle, etc. depending on the wave type) as well as to load a user-defined waveform.

Since these pre-loaded waveforms are defined by a “sample period”, the power units also allow to define how many times this period needs to be repeated at the output (it could be 1 time only so that only one period is performed up to an infinite number of cycles to have an infinite waveform at the output).

Also, these power units have an **embedded oscilloscope**, capable of acquiring 4 channels (e.g. DC-Link, output current, output voltage, etc.) at the data rate of the switching frequency.

Some of the main points of these power converters are hereafter presented, while the "Remote Control Manual" (for further information on remote control interfaces) and the "User's Manual" (for further information on the model itself, connections, interlocks, etc.) are available separately and are attached to this proposal for the purpose of having a direct reference to be consulted.

Communication can be performed via a standard TCP-IP (or UDP) 10/100/1000 MBit Ethernet connection and simultaneously via two fast SFP links (optical or electrical) that enable for the update rate of the output current to reach a 10 kHz value for fast feedback applications.

Standard resistive magnets are the typical addressees of these power supply units that guarantee high performances in terms of stability and noise as well of remote control and control system integration.

Internal protections against over-voltage (i.e. magnet stored energy), excessive current ripple, regulation fault, external interlocks, over temperature, earth-leakage current are implemented into the system with the same configurability level and easiness of use that all of CAEN ELS power supplies have always presented.

4.1. Current Sensing via 0-FLUCS Technology

Output Current sensing is performed via DCCT zero flux transducers of the 0-FLUCS series by CAENels or equivalent (Danisense, LEM). This technology guarantees higher stability and lower noise performances respect to other standard technologies for current sensing (Hall sensors, shunt resistors, etc.).

5. CONTROL SECTION

The proposed power converters will all have the same control section for the output regulation. This control section is composed by two boards, the control board and the carrier board, that are installed together into the control crate along with a power modules and cabinet interface board (see **Figure 5**). The boards that represent the base for the control and interfacing of the power converters are shown in **Figure 24**.

Figure 24 – control/interface and carrier boards

Each unit will be provided with a set of coupled boards that have the specifications described herein. The control/interface board is plugged onto the carrier board.

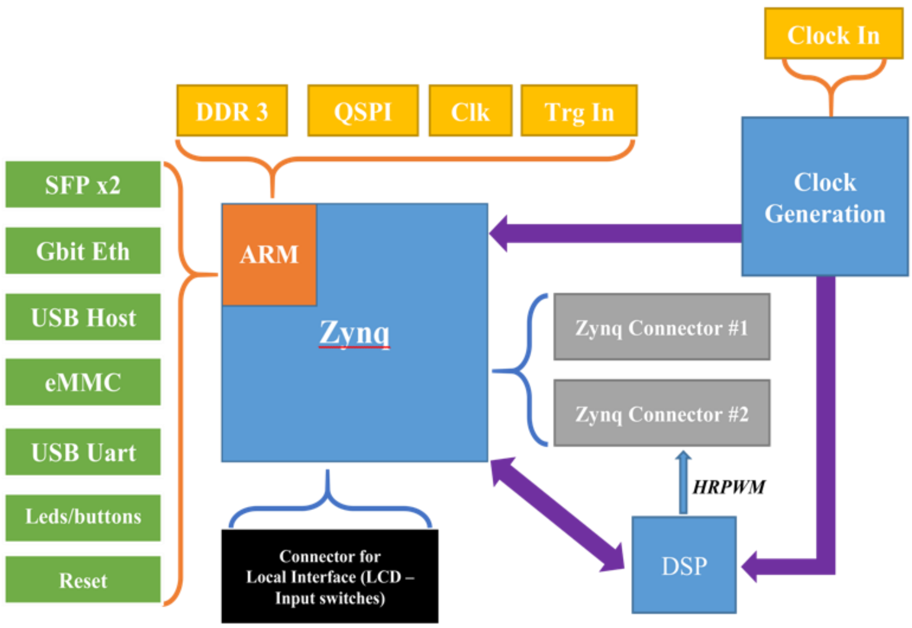


Figure 25 – control board building blocks

The digital **control board** includes these main building blocks shown in **Figure 25**:

- FPGA (Zynq)
- DSP (Texas Instruments)

The interfaces included in the board are the following:

- 10/100/1000 Ethernet;
- 2 x SFP+ (6.5 Gbps/channel);
- USB Host;
- eMMC;
- display and encoder control.

The on-board **FPGA** is used for digital output control algorithms and the **DSP** for High-Resolution PWM generation. A **Linux OS** (Yocto Project) is also embedded in the ARM processor.

The carrier board, on which the control board is plugged onto with two high-speed FCI connectors, is otherwise provided with:

- 2 x 24-bit@100 ksps ADCs for current and voltage readout (temperature stabilized);
- DC-Link, Temperature and Auxiliary analog readings (16-bit@100 ksps);
- I/O signals for interfacing with external protections;
- interlocks and status signals;
- a connector for future expansions.

The carrier board also embeds the power section to supply the active DCCT transducer with low-noise power at ±15V in order to have a direct, accurate, stable and precise current readout.

This control board design has been used in many different applications in the recent years, controlling many different types of power supplies (unipolar, bipolar) and different power stages (MOSFET-based, IGBT-based) with state-of-the-art performance. This includes the entire CAEN ELS line of modern commercial models as well as supplies delivered by *other* power supply companies. Said companies chose our control board, coupled with their power stage designs. That said, there are over 1,000 supplies currently driving magnets and being controlled by this board.

The output control has also been made for different types of applications, ranging from superconducting (low-voltage, high current) to high-voltage, voltage-mode setups.

5.1. Output Control

The output control is performed using a state-of-the-art digital architecture that includes a Zynq FPGA (SoC) and a DSP. This architecture allows reaching extremely high performance in terms of actuation and control of the output current (or voltage).

An example of the control loop that will be implemented is hereafter shown in **Figure 26**:

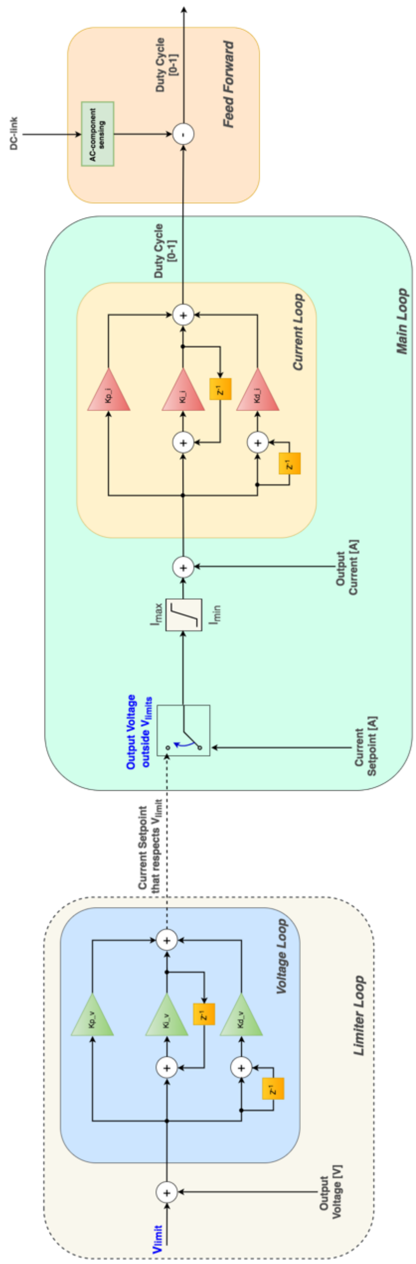


Figure 26 – current control loop with voltage loop and feed-forward – type 1

Another example of a control loop, with a nested current and voltage loop architecture, is shown hereafter in **Figure 27**:

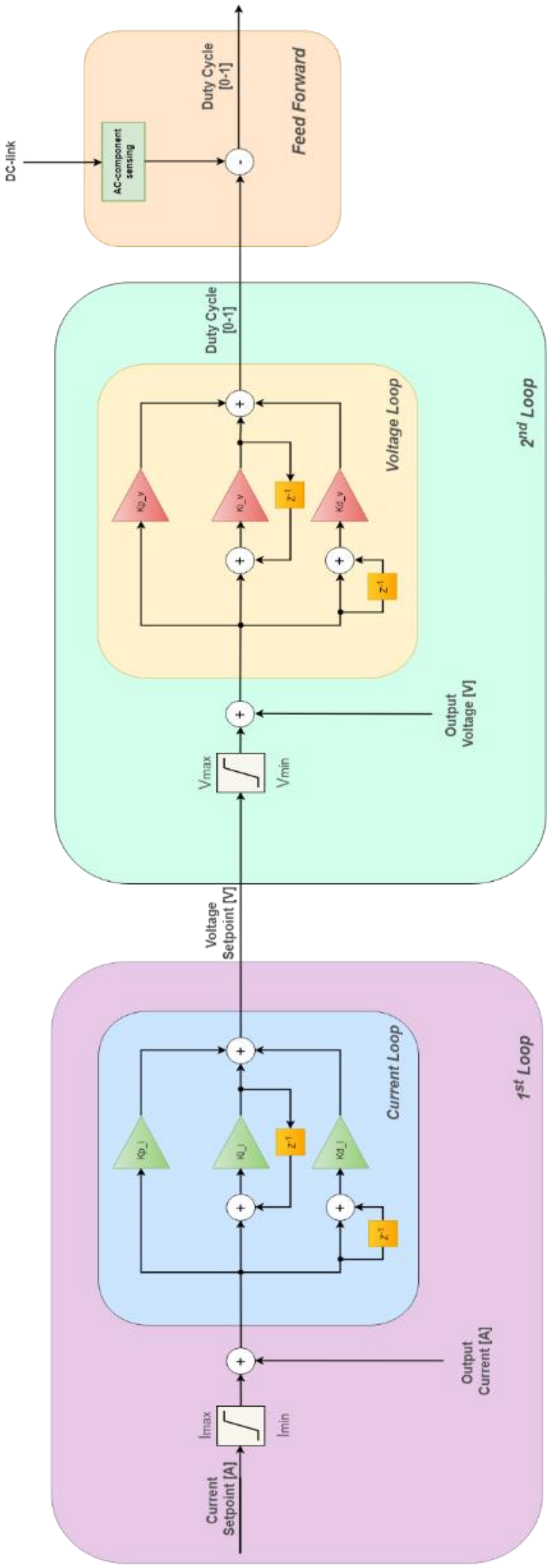


Figure 27 – current controlled and voltage control loop with feed-forward – type 2

6. DELIVERY

All items will be shipped to JLAB as requested in document **[b]**, Incoterms 2010.

As requested in document **[a]**, a written report of the progress status of the project will be provided to JLAB every two months after the contract signing by both parties.

The requested and the proposed delivery schedules are presented hereafter in section §12.3.

6.1. Warranty

The warranty period of the power converter will be of <u>12 months after the successful performance of the final acceptance test</u> at JLAB's site. The final acceptance test at JLAB should take place anyhow not later than 3 months after delivery.

6.2. Expected Input from JLAB for Installation

For the installation of the power converters, beside the crane operation, OCEM / MULTI is at disposal for any additional information and/or for remote assistance.

7. TABLE OF COMPLIANCE

A list of all the points described in the technical specifications and the compliance of the proposal is hereafter presented in Table 4.

Section of Technical Specifications Document [a]	***Compliant***	***Notes***
Testing	Yes	Test Protocol will be agreed upon parties. Full sized dummy load is offered as option
JLAB inspection/witness	Yes	
Shipment	Yes	
Prime Power AC Disconnect	Yes	
Single prime power supply voltage	Yes	
Operating Mode	Yes	
Controls	Yes	
External Interface / Interlocks	Yes	
Grounding	Yes	
Cooling Water	Yes	

Table 4 – Table of compliance

8. PAST PERFORMANCE

OCEM / MULTI – Energy Technology have supplied in the past years state-of-the-art instrumentation to different markets, focusing mainly on the particle accelerator market.

Our customers include the following major research centers worldwide (abbreviated list):

- CERN (Switzerland);
- Brookhaven National Laboratory - BNL (USA);
- SLAC (USA)
- TRIUMF (Canada)
- Jefferson LAB (USA);
- European Spallation Source – ESS (Sweden);
- Diamond Light Source (UK);
- CEA – Saclay (France);
- ALBA – CELLS (Spain);
- ELETTRA (Italy);
- INFN (Italy) many other centers and industries (for a more complete list please refer to the attachment).

Some samples of projects that explain our capabilities for providing custom and catalogue solutions are hereafter presented.

For more references, please refer to the attachment:

- 2021-CUSTOM_POWER_SUPPLIES_YearlyRev06_jlab.pdf

ESS – European Spallation Source – Sweden

Various Power supplies

OCEM Power Electronics, together with Caenels (in a temporary grouping), was assigned the bid for the delivery of more than 140 different power converters rated at 10 kW, 20 kW and 40 kW, for the European Spallation Source (ESS) in Lund, Sweden at the beginning of 2018.

The total value of the order was approximately of $1,300,000 (spare units yet to be added to this value), while the supplying process has been completed in the first months (2Q) of 2019.

Total Production:

No. 130 200 A / 50 V (10 kW) power converters

No. 6 400 A / 50 V (20 kW) power converters

No. 1 400 A / 100 V (40 kW) power converter

Total value of the supply: $1,300,000

References:

Roberto Visintini

Head of the Power Supply group at Elettra synchrotron

Email: Roberto.visintini@elettra.eu

TRIUMF – Canada

Power Supply for the Main Magnet of TRIUMF

OCEM Energy Technology has supplied the power converter, rated at 20 kA / 80 V for the main magnet of the TRIUMF cyclotron.

The power supply had very strict requirements, as the current ripple and short-term stability levels that had to be rated at 2 ppm/FS.

MAIN POWER SUPPLY RATINGS	
Output Current/Voltage	20.000 A / 80 V
Output Power	1600 kW
Mode of operation	DC
Regulation Mode	Constant Current
Topology	IGBT based modular converter
Current Ripple	≤ ± 2 ppm
Short Term Stability (5 min)	≤ ± 2 ppm
Long Term Stability (8 hour)	≤ ± 5 ppm
Power Factor	≥ 0,96
AC Input	3ϕ, 3-wire, 800 Vac
Cooling	Water
Footprint	630 x 255 cm (20.7 x 8.4 feet)

Total Production:

No. 1 20.000 A / 80 V (1.6 MW) power converter

References:

Dan Louie

Head of the Power Supply group at Triumf

Email: dlouie@triumf.ca

CERN – Switzerland

Capacitor Charge Power Supply

OCEM Energy Technology has designed, manufactured and installed a capacitor charger power converter for the Multi-beam I.O.T. Test Facility at CERN, in Geneva, Switzerland.

This capacitor charger was rated at 50 kV and 160 kW and it is shown in the below picture.

Total Production:

No. 1 50 kV / 160 kW Capacitor Charger

References:

Eric Montesinos

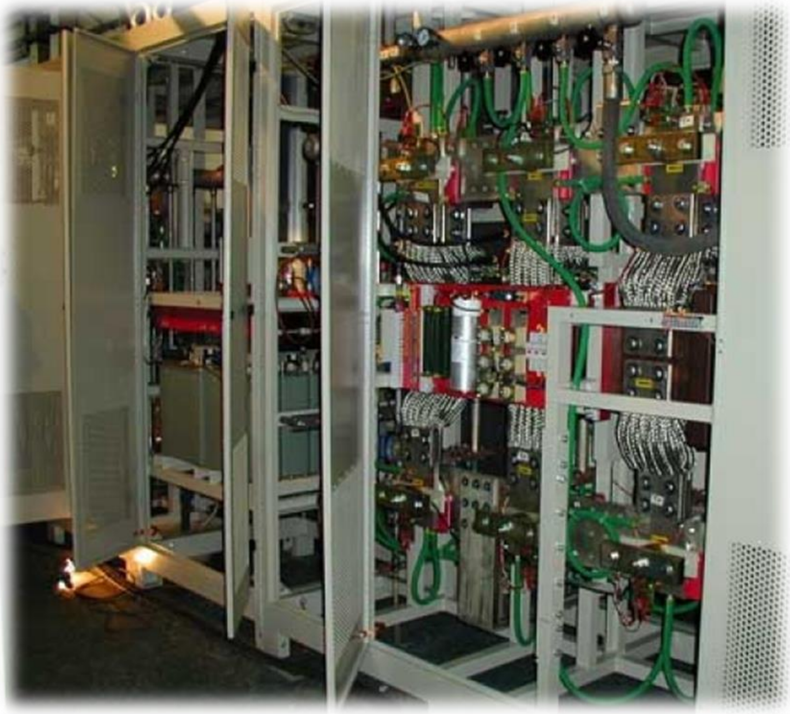
Head of the RF group at CERN

Email: eric.montesinos@cern.cfh

CERN

CERN LHC Dipoles PS

Nine (9) units were supplied to CERN for the LHC dipoles by OCEM. The specifications are listed hereafter. Output current is rated at 13 kA and voltage up to +/- 190 V.



Maximum current rating 13000 A

Nominal voltage rating ± 190 V

Current control range 80 – 100 % FS

Current resolution 18 bit

Current ripple < ± 10 ppm

Current reproducibility ± 10 ppm

Technology 12-pulse Thyristor secondary-side regulated

References:

Jean-Paul BURNET

Head of the Power Supplies group at CERN

Email: jean-paul.burnet@cern.ch

CNAO Pavia

CNAO HEBT Dipole Power Supplies

12 units have been supplied to CNAO for the HEBT dipole magnets. The specifications are listed hereafter. Output current is rated at 3 kA and voltage up to +/- 110 V.

- Maximum current rating 3000 A
- Nominal voltage rating ± 110 V
- Current control range 80 – 100 % FS
- Current resolution 18 bit
- Current ripple < ± 25 ppm
- Current reproducibility ± 25 ppm
- Technology 12-pulse Thyristor secondary-side regulated + Active Filter

References:

Mr. Giuseppe Venchi

Head of the Power Supplies group at CNAO

Email: giuseppe.venchi@cnao.it

DIAMOND Light Source

Diamond Storage Ring Dipole PS

This power supply was supplied by OCEM to Diamond light source in the UK and has the following specifications. For the storage ring dipole magnet power converter reproducibility is defined as the difference between the load current measured with an independent current transducer after 8 hours operation and the same load current measured one hour after the resumption of operation following a 16 hour break. The control and measurement electronics may remain energised throughout the period.

Resolution is defined as a change in the input reference signal that is followed by the output current.

Current ripple is defined as the peak-to-peak variation in the output current at frequencies from 5 Hz to 10 MHz, with a dc output current. The ripple must be achieved over the full current control range for the storage ring dipole power converter and up to the maximum dc output achievable with the booster power converters.

- Maximum current rating 1500 A
- Nominal voltage rating 531 V
- Current control range 50-1500 A
- Current resolution 18 bit
- Current accuracy ± 50 ppm (+ 75 mA)
- Current ripple < ± 10 ppm (± 15 mA)
- Current reproducibility ± 10 ppm (± 15 mA)
- Other features: Modular Technology, IGBTs, Hot swappability; Redundancy

References:

Mr. Colin ABRAHAM

Head of the Power Supplies group at DIAMOND LIGHT SOURCE

Email: colin.abraham@diamond.ac.uk

F4E – Fusion for Energy (Barcelona, SPAIN)

➔ http://www.fusionforenergy.europa.eu/mediacorner/newsview.aspx?content=791

ISEPS: Ion Source and Extraction Grid Power Supplies

The system includes:

n. 1 Anode Power Supply - ratings: 9.5 kV, 64 A (608 kW), modular

n. 2 Screen Grid Power Supplies - ratings: 2 kV, 5A (10 kW) modular

n. 2 Filament Power Supplies - ratings: 400 Vac, 25 Arms (10 kW)

n. 1 Control Grid Power Supply - ratings: -800 V / -100 V, 2 A

Extraction Grid PS: 12 kV, 140 A

Source Support PSs (5.000 A, 15 V ; 600 A, 30 V ; 11 other PSs)

4 RF Generators: 1 MHz, 200 kW each

Load connections and grounding

Insulation transformer 5 MVA; - 100 kV

Power Distribution inside HV Deck (6,6 kV; 400 V)

Power Distribution outside HV Deck (22 kV @ - 100 kVdc)

Interface, Control and Protection System

Cooling water distribution

Additional equipment, dummy loads, lighting, signal connections, tooling, spares

Total Production:

4 systems 2012 – 2020: two already installed

References

Mrs Muriel Simon

ITER Department – Heating and Current Drive Project Team, Neutral Beam Power Supplies (TJNAF)

Email: Muriel.simon@TJNAF.europa.eu

9. PROJECTED WORK LOAD AND FACILITY LOAD

9.1. Manufacturing resources

Since 2015 OCEM Energy Technology has its headquarters in a renewed building located in Crespellano locality, municipality of Valsamoggia, near to Bologna, in Italy; please find below some pictures.

Figure 28: OCEM premises, side view

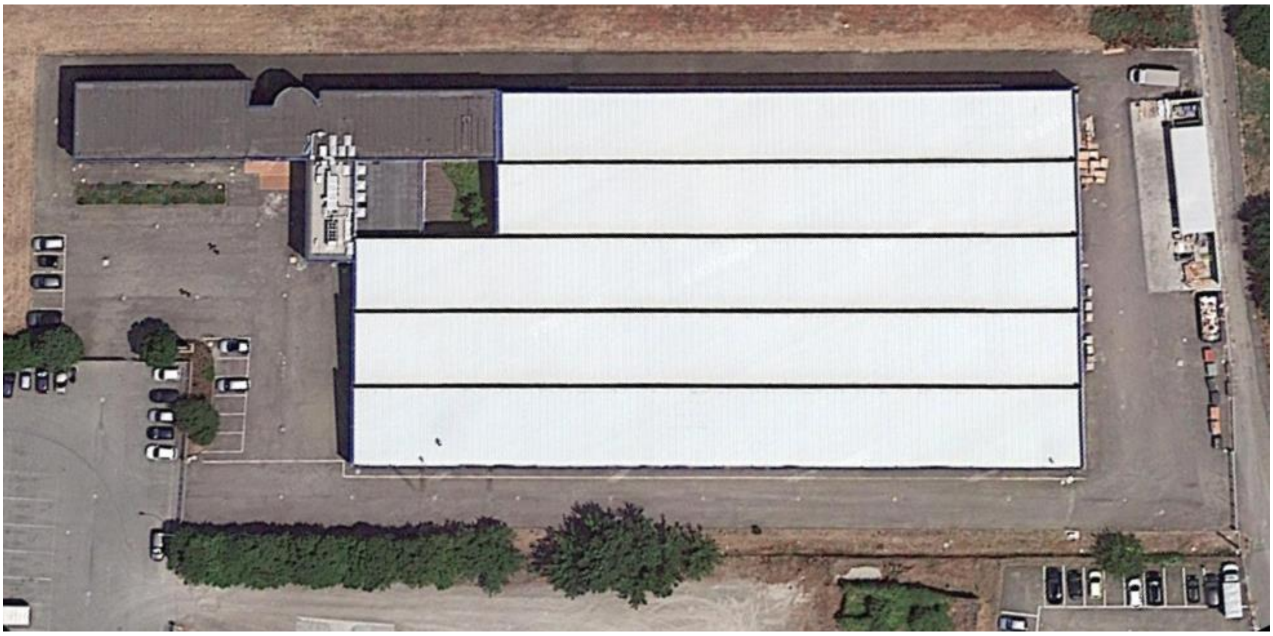


Figure 29: OCEM premises, aerial view

See below a planimetry of the facility and some picture of the manufacturing and test area. The total available area counts 6200 m^2, 3300 m^2 of which, on the ground floor, used for production and for testing activities.
The large production / test area has a flexible open space approach, without fix separations, which permits to easily adapt the space organization; in particular the separation between the testing areas and the production zone is made by solid but movable metallic fences.

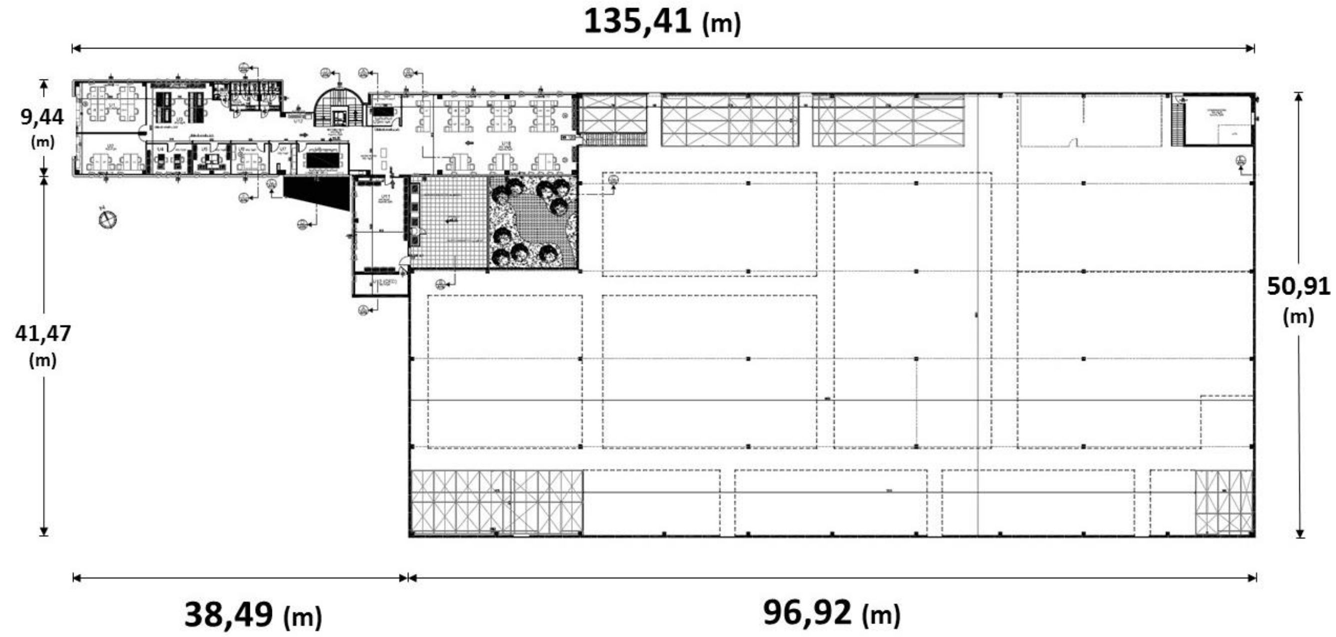


Figure 30: OCEM premises, planimetry of the facility

Figure 31: OCEM Production / Test area

Figure 32: OCEM Production / Test area

Figure 33: OCEM Test area

A solid network of external partner may extend the production capabilities with the furniture of standard components realized by design, like electronic boards, mechanical parts, water cooling, electrical wiring. In the organization of production at OCEM, every phase of sub-components production, both internal both external, is strictly controlled by OCEM engineering; moreover, it is in any case direct care of OCEM:

- the assembly and the wiring of critical parts, like High Voltage sections
- the final assembly,
- the test of any delivered unit.

Electricity distribution (AC three-phase) available in the testing area:

- 400 V internal distribution, with power up to 800 kVA, and programmable dedicated switchgears

- medium voltage internal distribution:
  - available voltages: 15 kV, 20 kV, 22 kV, 24 kV (easily selectable changing the taps in a dedicated proprietary autotransformer)
  - power up to 1.500 kVA
  - 24 kV switchgears.

Two independent water-cooling water systems are available, with independent pumps and several delivery points in the testing area:

- a fixed system for demineralized cooling water, with demineralization plant and tank of 10 m^3. The water conductivity can be easily set acting on the plant digital control panel, and can be adjusted (and maintained) down very low values.

- a fixed system for raw cooling water, closed circuit with a tank of 10 m^3.

Both the plants are ready to host a heater exchanger or cooling machine, to increase the cooling capability in case of very high power and/or very long (or continuous) tests.

The area depicted in *Figure 34 and Figure 35 is hosting the GSI Test Stand Power Supply (which will be delivered by October 2021) and two Kicker Magnet Power supplies both under final construction, both to be delivered by December 2021. This area can host the manufacture of the prototype, and in case, depending on the date of the order, the US and DS Torus power supplies.*
The testing phase for each power supply will be hosted in the area depicted in Figure 36, where the dummy load will be also located.

9.2. Design tools

OCEM have the best technologies to design, execute prevision by means of numerical simulations and support the production of its projects. With the focus on design tools, are present and used by OCEM engineers:

- ORCAD + PSPICE, software for design and simulation of electronic and electric circuits
- Cadence ALLEGRO, software for PCB design
- Autodesk INVENTOR, software for mechanical 3D design, and Autocad, software for 2D/3D mechanical design
- Electro Graphics IDEA, 2D CAD devoted to electric design
- Altera QUARTUS II, development suite Altera FPGA designing, compiling and debugging
- National Instruments LABVIEW, development suite for CompactRIO architecture designing, compiling and debugging
- Mathwork MATLAB with SIMULINK, FIXED POINT TOOLBOX and HDL CODE GENERATOR, software for numerical and control design and simulation, capable of direct generation of VHDL code to be integrated in the final system
- Plexim PLECS, both as standalone and as Matlab blockset, is a circuital simulation tool with high efficient simulation of power electronic models
- SIEMENS STEP7 + WINCC + TA-PORTAL, suite tool for Siemens PLCs development

Other C-language compiler for embedded microcontrollers, microprocessors and DSPs are in use at OCEM:

- MPlab for PIC devices
- Texas Instruments CC Studio
- Renesas E2studio.
- STM32 Cube and STM32 SDK from STMicroelectronics

Some references to the a.m. tools can be found on the Administrative envelope of the OCEM proposal for the tender.

OCEM disposes of integrated ERP for administration and production management. For managing of documentation and related workflow, OCEM adopts the KBS system, a DMS compliant with the requirements of ISO 9001.
OCEM disposes of Microsoft Project for specific topic of project management, widely used in OCEM PE activities.

10. INSPECTION AND TESTING

10.1. Measuring and test equipment

In order to demonstrate the conformance of products to the specified requirements OCEM uses instruments and equipment registered, identified and calibrated at regular intervals and kept efficient.
The activities mentioned above are carried out following OCEM Energy Technology procedure SC-PG-0001 (Measuring and test equipment management procedure) both for OCEM-owned equipment and equipment borrowed, or provided by the customer.
All measuring and testing instruments and equipment used by OCEM Energy Technology have features, accuracy and measurement range suitable for the purpose and are also used so as to ensure that the uncertainty level of measurement is known and consistent with the required measurement capability.

The measuring and testing equipment are used according to the following documents:

- procedure SC-PG-0001;
- technical procedures, specifically prepared by OCEM Energy Technology for each type of instrument;
- indications included in the quality plan of each product;
- written instructions supplied by the instrument manufacturer.

And the use is ruled as follows:

a) the measurements to be made are identified in the quality plans or pertinent documents (for instance in working plans).
Each measurement refers to procedures and instructions indicating the accuracy required, the equipment chosen and the forms to be used;

b) the inspection, measuring and testing equipment and devices which can affect the product quality are always identified, calibrated and adjusted at prescribed intervals or prior to use. The calibration intervals are established for each instrument.
Calibration is made against certified equipment (primary instruments) having a known valid relationship to nationally recognized standards (SIT calibration centers).
Where no standards exist, calibration and adjusting are made following technical procedures established by OCEM for each instrument. Identification is made following the OCEM procedure SC-PG-0001.

c) the calibration procedures (on paper or in the computerized calibration software), used for each equipment, report the type of equipment, identification number, location, frequency of checks, checking methods, acceptance criteria and the action to be taken when results are unsatisfactory;

d) the technical procedures for the use of inspection, measuring and testing equipment ensure that they are used in such conditions as to obtain necessary accuracy and precision;

e) OCEM Energy Technology procedure SC-PG-0001 regulating the inspection, measuring and testing equipment indicates the types of marks (labels, etc.) and approved documents used to identify this equipment and to show their calibration status;

f) every calibration must be recorded and the pertinent documents must be held as quality records;

g) OCEM Energy Technology procedure SC-PG-0001 relating to measuring, inspecting and testing equipment states that if equipment is found out of calibration, OCEM must assess and document the validity of previous inspection and test results made by means of the same equipment;

h) the technical calibration procedures establish the methods to ensure that calibration is made under suitable environmental conditions;

i) both administrative and technical procedures assure that handling, preservation and storage of inspection, measuring and testing equipment are such that the accuracy and fitness for use is maintained;

j) the company's procedures safeguard access to calibration of inspection, measuring and testing equipment, including both hardware and software, by means of seals or other protective devices, to prevent adjustments which would invalidate the calibration setting.

Where hardware (i.e. jigs, fixtures, templates, patterns) or computer software are used to perform inspections and testing, the technical office draws up suitable procedures or instructions establishing that these instruments must be proven capable of verifying the acceptability of products prior to release for use during manufacture and must be verified at established periods. The extent and frequency of such proving is established.
Records are maintained as evidence of control.
Measurement criteria are made available, when required by the customer or its representative, for verification that they are functionally adequate.

10.2. Control of measuring and test equipment

Measuring and test equipment are controlled showing evidence of:
- equipment identification and calibration status;
- proper use (range, precision, ...);
- record of proper calibration.

Test records clearly identify any test equipment that has been used and its calibration status.

10.3. Inspection and quality audits

All "assessment reports" relating to external suppliers, all programmed audits, inspections, etc. are indicated and the relating records are identified and recalled in the Control Plan.

OCEM shall take all necessary measures to allow the Customer unrestricted access to all of OCEM's documentation, premises and personnel (including that of its Subcontractors) during all stages of the Contract for the purpose of such audit, review, surveillance and inspection as Customer may consider necessary.

The Customer, or his representatives shall be permitted to take photographs and / or video recordings of any activity relating and limited to the Contract. The material so obtained shall remain confidential.

10.3.1. Audits and Surveillance

The Customer or his representatives may carry out periodic planned and documented audits, reviews, surveillance and inspection of the quality system being operated by OCEM Energy Technology to verify compliance with all quality and technical aspects of the Contract.
These activities may be extended to OCEM's Subcontractors, and OCEM Energy Technology shall ensure that Customer's right to conduct periodic audits, reviews, surveillance and inspection of the quality system being operated and to verify its compliance with all quality and technical aspects of the Contract, is incorporated into any subcontract. Should any deficiency in the quality system exist, OCEM shall implement, or ensure that the Subcontractor implements, corrective actions, in accord with a timetable agreed by OCEM Energy Technology.

11. SUBCONTRACTORS AND SUPPLY CHAIN

The supply chain and the purchase process are managed and controlled in compliance with the dedicated procedures listed below.
Suppliers / Subcontractors are followed; they are selected according to certain determined criteria.
The main procedures are contained in the following:

- Document A[8]: Quality Manual (AQ-PG-0001) § 8.4: "Control of external procurement of goods and services";

Document A[5] AQ-PQ-0010 "GRPS Quality Plan" at § Q6 and § I7 is an example of quality documentation.

These documents are for internal use, but can be shared upon request.
In particular, the roles and responsibilities are identified, as the operating procedures for the proper management of:

- Requests to suppliers;
- Examination of Offers and Choice of the Supplier;
- Issue of Purchase Orders and Order Confirmations;
- Management of purchase orders, and any changes;
- Follow up;
- Archiving of documents.

In order to manage the activities related to the contract, the materials are divided into the following categories:

- Long Lead Time Materials (LLT);
- Not Long Lead Time Materials (NLLT);
- Exceptionally Long Lead Time Materials (ELLT);

the planning of materials procurement will be detailed in the dedicated Time Schedule, that takes into account the different lead times of these three categories.

11.1. Components traceability

During the relevant Detailed Design Phase, OCEM Energy Technology will propose a list of the components where traceability is necessary; the list will be discussed and agreed with the customer.

Each component of this list will be identified with:

- ID (code)
- serial number (or production batch).

The relevant information and documents containing all the data that allow going back to the production process, material utilized, manufacturer, tests etc. (like manufacture records, production batch information, test reports, conformity declarations, etc., depending on the needs of each specific component) will be recorded with reference to ID and serial number.

At any time, the ID and the serial number will allow identifying the records containing the information about the traceability of the component;
Records of the traceability of each component will be stored and kept by OCEM for at least 10 years (or the regulatory period of time, whichever is longer).

11.2. Non-compliances identification, resolution and elimination

The Identification, resolution and elimination of Non-Compliances is described in the following procedures (available upon request):

- A[8] AQ-PG-0001 - Quality Manual § 10.2: "Non conformità e azioni correttive";
- A[11] AQ-PG-0008: "Non Conformità, azioni correttive e preventive".

Again, as an example, AQ-PQ-0010 "GRPS Quality Plan" A[5] at § Q1.2 up to Q.1.2.4.3 can be shared upon request.

In particular the procedure AQ-PG-0008 provides the management of non-compliance referring to:

- About origin: Internal (OCEM), by Supplier, by Customer;
- About type: Product, processes and services;

The procedure identifies roles and responsibilities, the operating procedures for the correct management of non-conformities (segregation of non-compliant material, NC analysis, identification and registration, etc.) and for resolution, Corrective Actions and Preventive Actions, with Analysis of Effects and Causes, definition of actions, verification implementation and effectiveness.

12. PROJECT MANAGEMENT,ORGANIZATION AND MANUFACTURING RESOURCES

12.1. Project management and key figures

All Project Management Best Practices will take place to protect Project Planning:

- Set Up of Project Organization. A Project manager will coordinate the project **Core Team**. The Core team represents all "swim lanes" of project (Engineering, Supply Chain, Quality Assurance, Operations, etc).
  Every Core Team member will coordinate his **Extended Team**. Every extended team is responsible of a specific project swim lane and will take care of all related activities. E.g. Extended team for Operations will take care of all related tasks (Assembly, etc). Please have a look at organization set-up, *Figure 37*.
- A structured Project Governance will be in place: weekly pulse meetings to control project status, Design Review meetings to control Technical Decisions, Risk assessment sessions to control and mitigate risks, etc
- Risk Management logbook and mitigation strategies will be available
- Stakeholder management will take place to align key suppliers and to align Customer. Recurrent alignment meetings will be organized to align Customer on project status
- Contractual meetings will be organized by Reference Engineer: **Critical Design Review meeting (CDR), Production Readiness review meetings (PRR), System Acceptance Review meeting (SAR)**
- **Reference Engineer** will be the Project Manager or his delegate.

In the following figures, the project organization set-up is given.
The Core Team of the project is presented in *Figure 37*.
Two examples of Extended Teams are presented in *Figure 38* and *Figure 39*.
The summaries of CV for Key Project Team Members are available upon request.

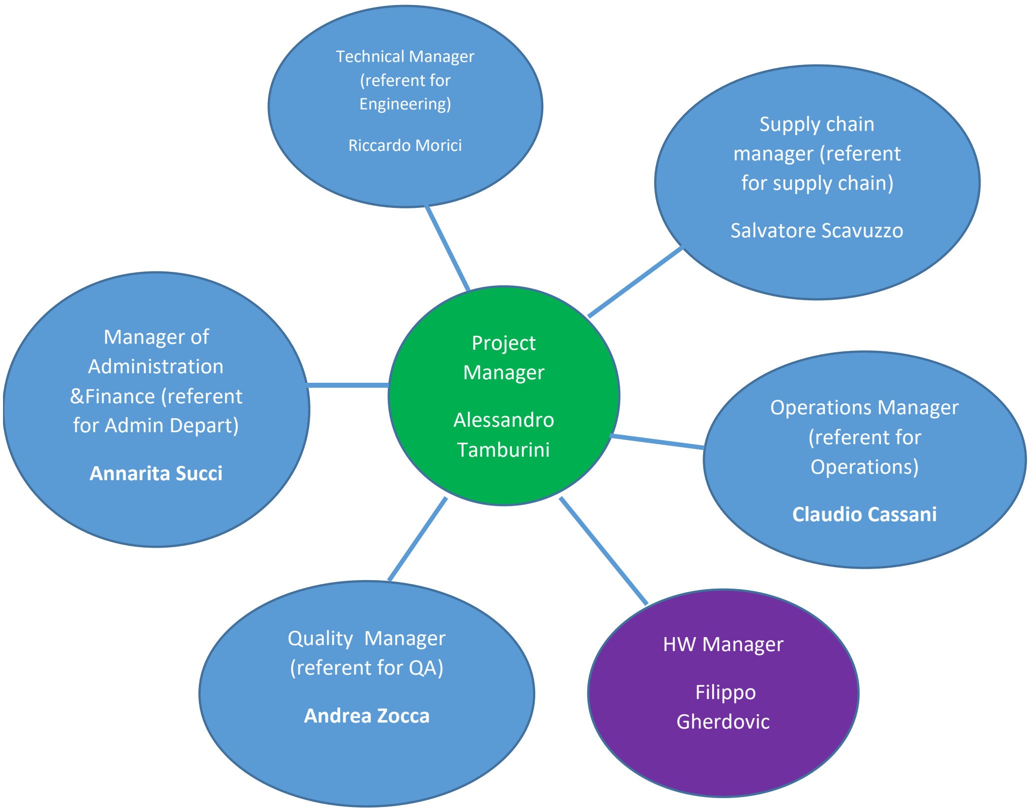


Figure 37: Project Core Team

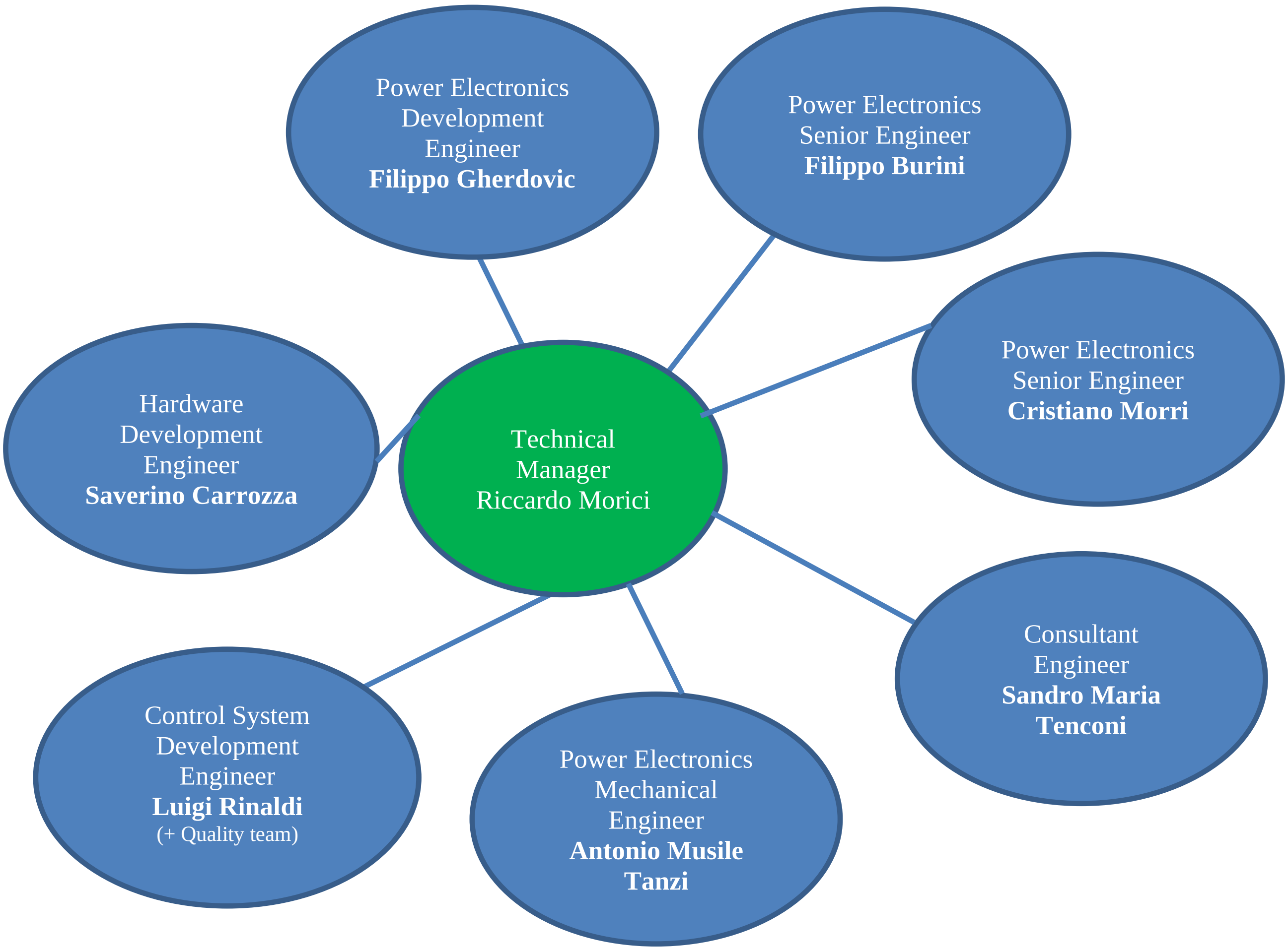


Figure 38: Engineering Extended Team (example of extended team)

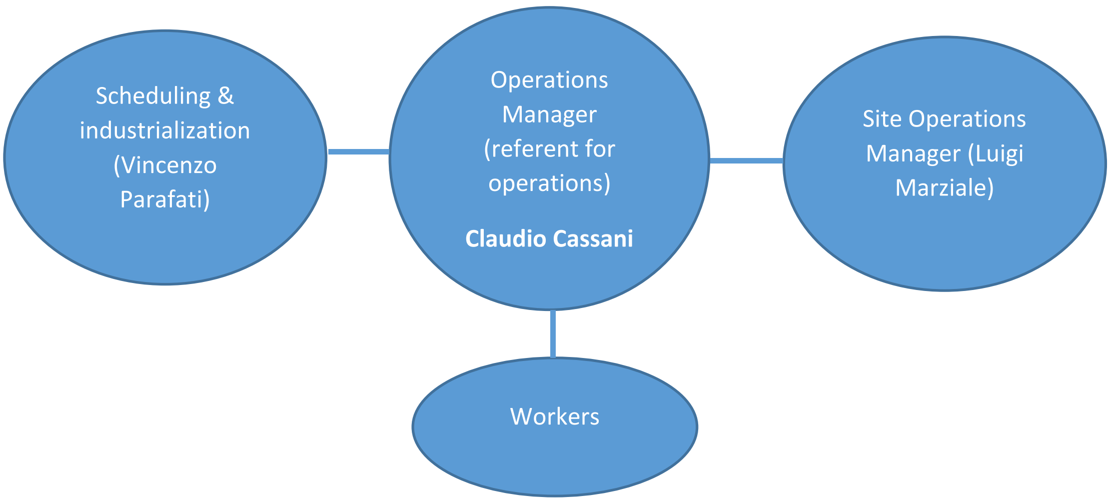


Figure 39: Operations Extended Team (example of extended team)

12.2. Risk management and mitigation plan

A preliminary Risk Assessment session took place to explore main risks, to estimate their probability/severity and to identify potential mitigation strategy and actions.
No relevant risks have been identified on technical dimension.
Main risks have been identified on duration of procurement with potential impact on project timing, especially due to the actual market contingency for semiconductor devices. Mitigation strategy will focus on parallelization of activities to create contingency.
A complete Risk assessment session will take place before TDR milestone; outcomes will be shared with customer to collect feedback.

12.3. Timing and schedule

After a preliminary risk analysis and evaluation of related potential impacts on project schedule, OCEM proposes a scheduling scenario based on the following key planning points:

- Activities on First unit (at OCEM site) will focus on
    a. Power converter validation
    b. Verification, Validation and PRE- FAT
    c. Full testing
    d. FAT
    e. SAT at customer site
- 2 assembly positions and 1 testing positions for the Series Power Converters will be available at OCEM site for series production. This approach will parallelize activities, contains project duration and mitigates risk of project delay
- If mitigation of a project delay will be needed, second testing position will be activated. Assembly space and resources to increase parallelization approach has been considered in mitigation plan, in case further delay will take place and further mitigation will be needed.
- Procurement of Long Lead Time material will start ASAP, to protect Project Timing.

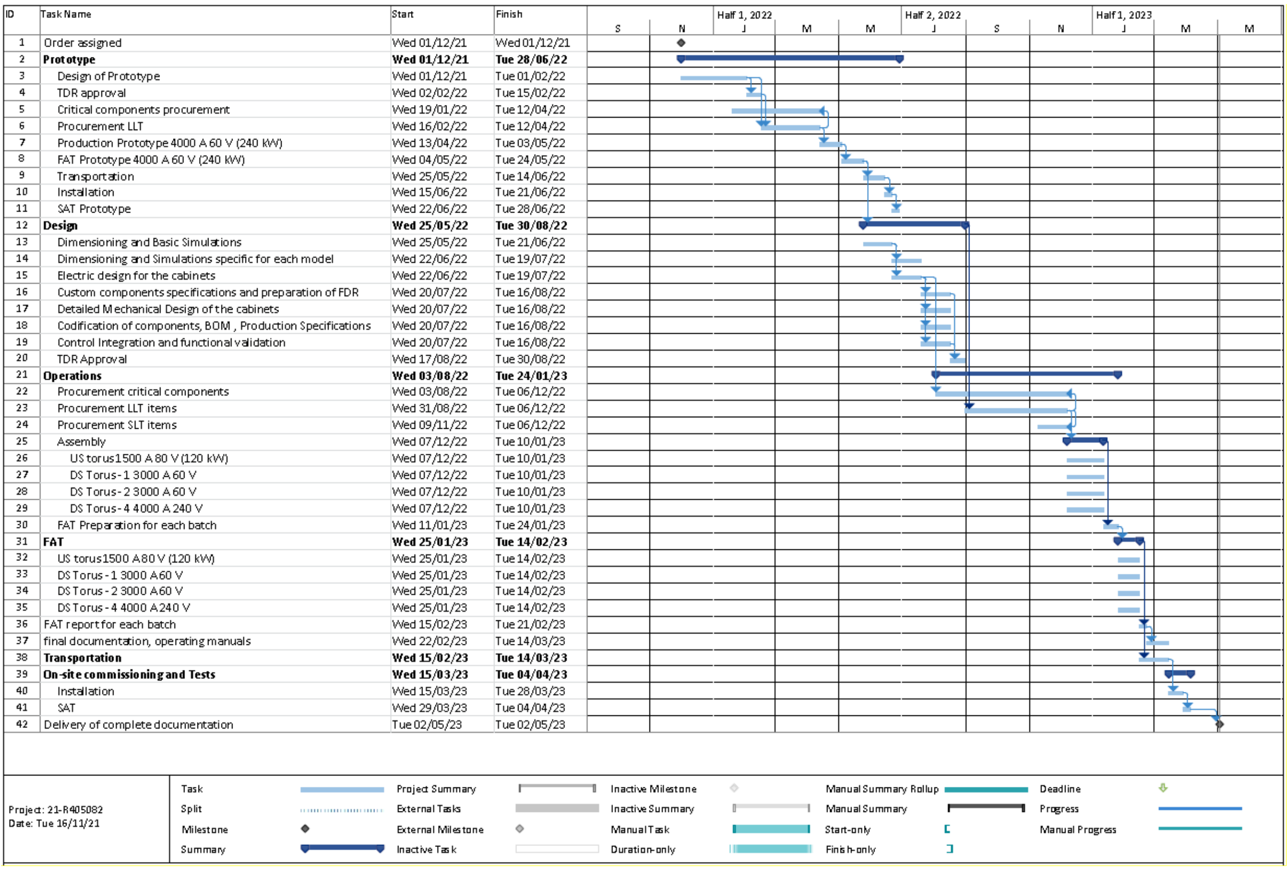
12.4. Project schedule GANTT

The resulting preliminary project schedule is presented in *Figure 40*. It assumes to have the contract signature on **December 1st 2021** (to get a specific T0 date for planning purpose).

Column description:

- **Activity name**: name of Milestones or activities
- **Start:** Starting date of Activities or Milestones
- **Finish**: last date of Activities or Milestones

The completion of manufacturing is foreseen on the **4th May 2022**, and Factory acceptance tests are foreseen to be completed by **May 25th 2022**, i.e. after 174 days after receiving the order.
Then the power supply will be shipped to JLAB, with the arrival foreseen by the June 15th 2022, i.e. 196 days ARO.



ID	Task Name	Start	Finish
1	Order assigned	Wed 01/12/21	Wed 01/12/21
2	**Prototype**	**Wed 01/12/21**	**Tue 28/06/22**
3	Design of Prototype	Wed 01/12/21	Tue 01/02/22
4	TDR approval	Wed 02/02/22	Tue 15/02/22
5	Critical components procurement	Wed 19/01/22	Tue 12/04/22
6	Procurement LLT	Wed 16/02/22	Tue 12/04/22
7	Production Prototype 4000 A 60 V (240 kW)	Wed 13/04/22	Tue 03/05/22
8	FAT Prototype 4000 A 60 V (240 kW)	Wed 04/05/22	Tue 24/05/22
9	Transportation	Wed 25/05/22	Tue 14/06/22
10	Installation	Wed 15/06/22	Tue 21/06/22
11	SAT Prototype	Wed 22/06/22	Tue 28/06/22
12	**Design**	**Wed 25/05/22**	**Tue 30/08/22**
13	Dimensioning and Basic Simulations	Wed 25/05/22	Tue 21/06/22
14	Dimensioning and Simulations specific for each model	Wed 22/06/22	Tue 19/07/22
15	Electric design for the cabinets	Wed 22/06/22	Tue 19/07/22
16	Custom components specifications and preparation of FDR	Wed 20/07/22	Tue 16/08/22
17	Detailed Mechanical Design of the cabinets	Wed 20/07/22	Tue 16/08/22
18	Codification of components, BOM , Production Specifications	Wed 20/07/22	Tue 16/08/22
19	Control Integration and functional validation	Wed 20/07/22	Tue 16/08/22
20	TDR Approval	Wed 17/08/22	Tue 30/08/22
21	**Operations**	**Wed 03/08/22**	**Tue 24/01/23**
22	Procurement critical components	Wed 03/08/22	Tue 06/12/22
23	Procurement LLT items	Wed 31/08/22	Tue 06/12/22
24	Procurement SLT items	Wed 09/11/22	Tue 06/12/22
25	Assembly	Wed 07/12/22	Tue 10/01/23
26	US torus 1500 A 80 V (120 kW)	Wed 07/12/22	Tue 10/01/23
27	DS Torus - 1 3000 A 60 V	Wed 07/12/22	Tue 10/01/23
28	DS Torus - 2 3000 A 60 V	Wed 07/12/22	Tue 10/01/23
29	DS Torus - 4 4000 A 240 V	Wed 07/12/22	Tue 10/01/23
30	FAT Preparation for each batch	Wed 11/01/23	Tue 24/01/23
31	**FAT**	**Wed 25/01/23**	**Tue 14/02/23**
32	US torus 1500 A 80 V (120 kW)	Wed 25/01/23	Tue 14/02/23
33	DS Torus - 1 3000 A 60 V	Wed 25/01/23	Tue 14/02/23
34	DS Torus - 2 3000 A 60 V	Wed 25/01/23	Tue 14/02/23
35	DS Torus - 4 4000 A 240 V	Wed 25/01/23	Tue 14/02/23
36	FAT report for each batch	Wed 15/02/23	Tue 21/02/23
37	final documentation, operating manuals	Wed 22/02/23	Tue 14/03/23
38	**Transportation**	**Wed 15/02/23**	**Tue 14/03/23**
39	**On-site commissioning and Tests**	**Wed 15/03/23**	**Tue 04/04/23**
40	Installation	Wed 15/03/23	Tue 28/03/23
41	SAT	Wed 29/03/23	Tue 04/04/23
42	Delivery of complete documentation	Tue 02/05/23	Tue 02/05/23

Figure 41 GANTT.

12.5. Risk management and mitigation plan

A preliminary Risk Assessment session took place to explore main risks, to estimate their probability/severity and to identify potential mitigation strategy and actions.
No relevant risks have been identified on technical dimension.
Main risks have been identified on duration of procurement with potential impact on project timing.
Mitigation strategy will focus on parallelization of activities to create contingency.
A complete Risk assessment session will take place before TDR milestone. Outcomes will be shared with customer to collect feedback.