# Magnet Power Supplies for TESLA

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# Content

# Introduction

TESLA (Terra Electron Volt Energy Superconducting Linear Accelerator) is a design for an accelerator using superconducting cavities to accelerate the particle beam. It will have a total length of 33 km. A principle overview is given in Fig. 1.
For bending and focussing the particle beam dipole and quadrupole magnets are used. The main linac contains a large number of superconducting magnets, which are nearly 50% of the overall number. In the other subsections of the accelerator from injection to the beam dump a large number of different normal conducting magnets are used. Overall a few thousands of magnets will be installed in TESLA. According to the position and function of the subsection these magnets have different ranges of power, voltage and current.

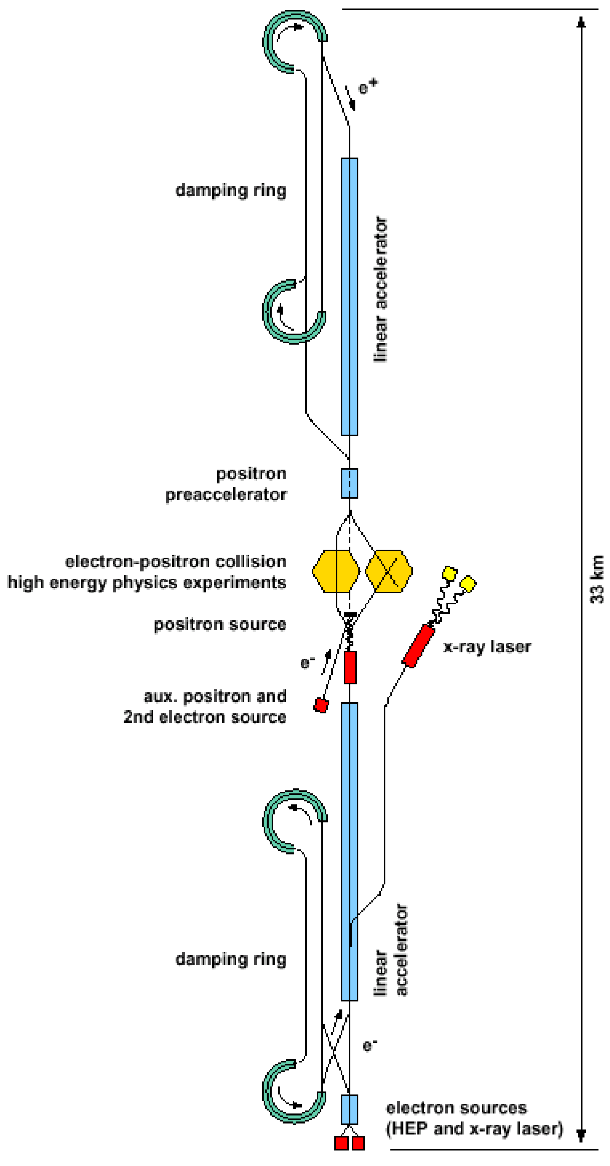


Fig.: 1 Principle overview of TESLA

The magnets are fed by power supplies with a very precise DC current. The nominal currents of theses supplies vary between 20 A and 4000 A. The accuracy is in the order of $10^{-4}$ to $10^{-5}$ current variation/nominal current ($\Delta I/I_{nominal}$). There is a lot of knowledge about dealing with large numbers of precision DC power supplies at different laboratories in the world, e.g. DESY, CERN, Fermilab and SLAC. Nevertheless TESLA has specials demands on reliability, maintenance, cooling etc. For example a lot of power supplies will be installed inside the tunnel near the accelerator modules, and access in case of failure is no longer possible during normal operation. By special design of the supplies, failures shall be minimized and an additional redundancy concept has been investigated to prevent single power supply failures affecting accelerator operation.

## General criteria for the design and operation

Due to the large number of units it is essential to have common design points such as uniform control system, regulation and power supply controller (PSC).
Whenever possible the same type of power supply shall be used. As explained later this concept can be used for most of the steering magnets.
In general the components shall be overdesigned and not go to the edge of the technical specification.

### Basic assumptions

For the design and cost estimate of the power supplies some assumptions have to be made:

- The power supplies are DC supplies
- Radiation level
  The assumed 10 years dose is max. 100 Gy as an integrated dose. The power supplies have to survive this dose. When single events of high radiation do occur they may cause a damage of components. The electronic is not hardened for these events.
- Cooling water
  Input temperature 30°C
  Output temperature 50 °C
  Deionized water is used
  The cooling water in and outlet is near the power supplies
- Air temperature
  The air temperature is assumed less than 30 °C. The temperature change is less than 10 °C
- Three phase mains
  The mains distribution is assumed available. This is either a distribution system that is installed inside the tunnel or a switch board in the halls.
- Magnet interlock, Permit system, Power supply controls, Bus systems for data transfer
  These systems are available from the control groups. The connection to these systems require only some cabling. The power supply controller as interface to the data bus system is part of the power supply.
- Accuracy
  The general accuracy of the power supplies is $\Delta I/I_{nominal} = 1*10^{-4}$ . Only a few power units will have an accuracy of $\Delta I/I_{nominal} = 1*10^{-5}$
- Redundancy concept
  In case of a trip of a power supply the accelerator operation shall not be interrupted for more than a few minutes
- Maintenance
  There is one maintenance day every four weeks. On these days there is no access restrictions for power supply repairs.

### Interface of the power supplies to the main control room

The power supplies of the accelerator have to be remote controllable from the control room. The power supply controller is the interface between the control room and the power supply.

It has to turn the supply on and off, the current set points have to be given, actual status, he current and voltage values have to be read back. Additionally in case of failure a remote diagnosis has to be possible to see what failure occurred and how much damage happened. This is of special interest in the main linac since not every failure turns down the power supply.
In [1] the Switched Ethernet is mentioned as a possible new bus system. The protocol used is the Internet Protocol (IP-protocol). Using this combination opens a wide range of data transfer between the control system and a single power supply. This can be used for remote failure tracking. With the use of the Internet this data can be available for the control room and also for the maintenance groups that are not directly related to the control room.
With Internet software inside the power supply it will not be necessary to run special software on the read out computer of the maintenance group, since a standard internet browser will give access to the status of the supply. However for running the accelerator the software has to be much more elaborate.
Since the development of components in this area is continuously and rapidly on-going, no final solution is presented here. However today power supply controllers based on Internet technology can be bought from industry. PLCs (Programmable Logic Controllers) with interfaces supporting this technology are presented in [3].

## Design concept of small power supplies

The major part of the power supplies that will be installed has a power of less than 1 kW. Here about 800 PS with unipolar current of 50 A and 100 A are needed. The number of steerers adds up to more than 3000 units.
These power supplies will be constructed in a highly redundant way. The aim is that a failure inside the power supply does not lead to a trip of the entire unit. To do this the power part is split into many small power boards. These boards have the values of 25 A/10V. With a redundancy factor the number of devices can be determined that may fail without an overall trip, e.g. the power supply 100 A/ 10 V will have six of these boards. Two boards may trip and still the entire current can be supplied by the remaining boards. The tripped boards are disconnected either via fuses.
For the bipolar power supplies the same boards will be used and a semiconductor polarity switcher is installed to allow the current to flow in both directions through the magnet. The technical realization of these power supplies is investigated and described in [3] and added as appendix to this report. Fig. 2 shows the principle of this design.
Furthermore a minimum number of single point components are used. Single point components are components that can not be doubled to increase the redundancy. Still there will be parts that are unique.
One part will be the PSC and regulation. A simply doubling will not be enough since it is not clear which one of the two controllers is the failing device. Having three controllers is not cost effective. When looking at the failures of the controller a software failure seem most probable, therefor the installed software has to be rebootable.
The units will be installed into 19” electronic racks. The mounting into the racks and the testing will happen directly at the vendors factory. The fully equipped containers will be transported and positioned to the required location.

### Cooling of the power supplies

The power supplies have a high efficiency: therefore the losses in the electronics can be handled with air cooling. In order not to heat the electronic racks nor to give this heat into the tunnel the electronic racks have to be water cooled.

Inside the electronic racks is a forced air cooling with an air-to-water cooler. This air/water cooler is connected to a cooling machine which then transmits the energy to the tunnel water. The cooling machine will work for nine electronic racks.

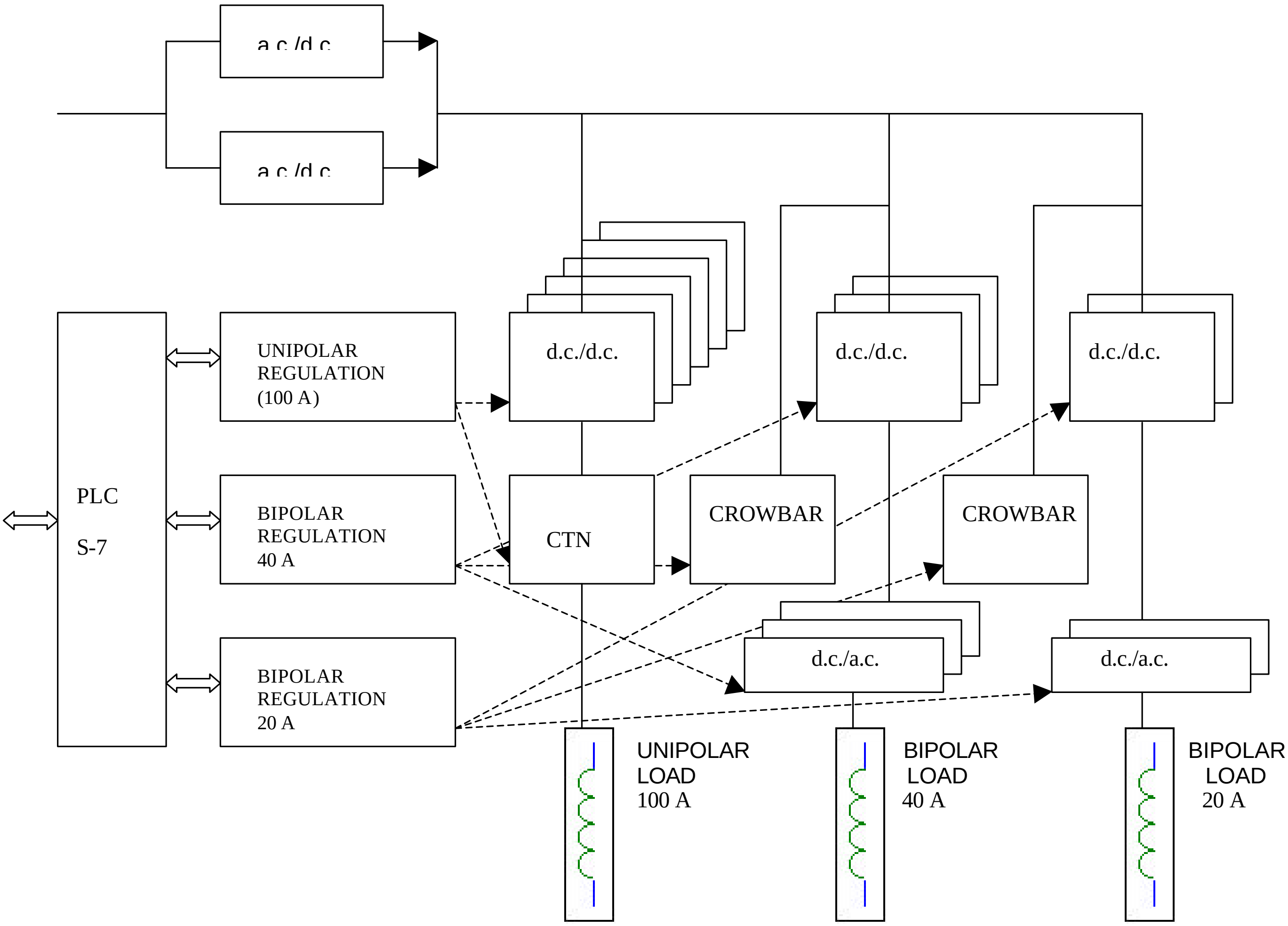


Fig. 2.: General schematic of the redundant power supplies for the Main Linac.

Repair

There are a few approaches for the maintenance. The power supplies have a modular design. It is not expected that the entire power supply fails but single modules will break down without tripping the supply. With the adequate software the maintenance group is aware of amount of modules inside the power supplies that are broken. On the maintenance day the broken modules can be replaced. They can easily be transported by carriage. When looking at the expected failure rate this is the most effective way of repair.
If there is a severe failure with a power supply the entire container holding the electronic racks can be exchanged using the monorail.

## Medium size power supplies

The medium size power supplies have electrical values of up to 600 A and 200 V. These units will be built as switched mode power supplies. They are used for normal conducting magnets in the beam lines. The buck converter is a low cost and efficient solution as switched mode supply. The buck converter consists of a pre-rectifier, a semiconductor switch with free-wheeling diode and a passive LC-filter as shown in Fig. 3. Via the semiconductor switch the load is connected to the output voltage of the pre-rectifier. With a pulse width modulation (PWM) the desired voltage and currents can be regulated. These power supplies are available on the market by different vendors. As semiconductor switch MOSFETs and IGBTs can be used.

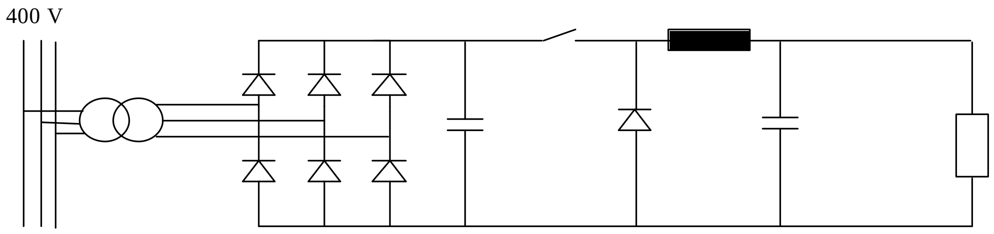


Fig.: 3 Schematic of the buck converter

Cooling

Power supplies of this size have to be water cooled in order to keep the volume low. The temperature difference of 20 °C that is needed for the water cooling can be achieved by the power part without a further cooling system. The electronics is not cooled any further

Repair

In case of a trip of a power supply the entire unit has to be exchanged. This has to be done during a maintenance day. The exchange has to be done with special crane equipment or with the monorail.

## Large size power supplies

These power supplies exceed the values of 600 A or 200 V in either one or both values.
The most cost effective way to build these power supplies is using SCR technology. These power supplies will be built in B6 or B12 bridges with passive LC-filters. A schematic of a B6 -bridge is shown in Fig. 4. The required voltage for the magnet is determined by a transformer that is either built into the same rack or as external transformer. The required currents of 4000 A and the voltages of 1200 V are no problem for this technology. Due to the size the tunnel installation is difficult With the occurring currents it cannot be guaranteed that there are no magnetic stray fields coming from the power part. In order not to disturb the accelerator beam these supplies are not installed in the tunnel.

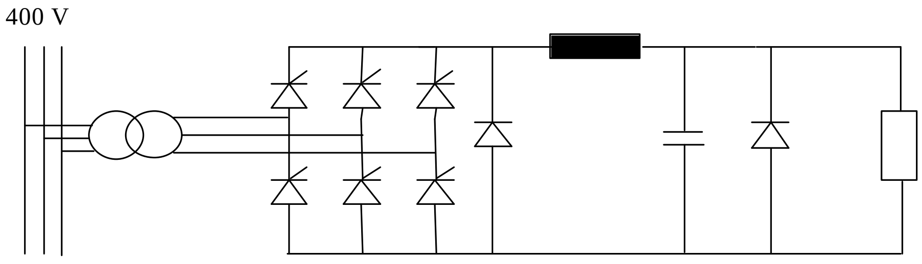


Fig. 4 Schematic of a 3 phase SRC bridge with passive filter

### Cooling

Power supplies of this size have to be water cooled in order to keep the volume low. The needed temperature difference of 20 °C that is needed for the water cooling can be achieved by the power part without further cooling machine.

### Repair

With the chosen redundancy concept explained in the next chapter the broken power supply is disconnected from the magnet and replaced by a spare supply. The broken unit can then be repaired at a later time. According to the experience at DESY just the broken part will be replaced in most cases without changing the whole power supply. Nevertheless the units will be built in such a way that they are exchangeable with crane or a fork lift.

## Failure handling and redundancy concept

Since TESLA is a machine with high installation and running cost the down time of the machine has to be minimized. The common way of repair in today's accelerators is that in the event of a power supply trip the technicians go or drive to the broken supply to repair or exchange parts or the entire supply. Due to the size of TESLA (and therefor the long distances), even the time to arrive at the tripped unit is too long, not to mention the repair time itself. To come back to operation within a few minutes a redundancy system has to be developed.

There are two possibilities of reacting to the trip:

- The function of the magnet can be replaced by other magnets with simple current setting changes of the nearby magnets

- The function of the magnet can not be replaced and the power supply has to be exchanged

If it is possible to replace the function of the magnet the control system has to find the adequate parameters of the optics. Then the new current settings are given to the remaining power supplies and the machine can go back to operation.
It is assumed that all steering magnets can be replaced with this technique.

In case the function of the magnet can not be replaced in the optics another solution is used. The small power supplies will be built in a highly redundant way. There are more components in parallel installed than are necessary for the operation. For larger power supplies this becomes to costly. The solution is to have a spare for a group of units. In case a power supply trips the magnet is disconnected and connected to the spare supply. In this system the redundancy can be increased by adding more spare supplies. If the power supplies are installed in the tunnel additional cabling has to be installed as well. Here it is sometimes cheaper to have another power supply. The cost is lower and the reliability is increased.
Unfortunately for large power supplies it is sometimes necessary to replace these units one for one.
As switches, contactors with magnetic locks or motor driven switches will be installed. These units have two stable positions. Once they are in one position they do not need any further energy to remain in this position. Only when the position has to be changed the unit is energized. By this a safe operation even in case of a power loss is guaranteed.

## Calculated reliability of the power supply system

The reliability of a technical system can be calculated. With the help of these numbers the amount of redundancy inside the system can be evaluated.
The quality of the units is given by the Mean Time Between Failure. The better the design the higher is this number. This value can be derived from the components that are used. Usually the vendor has to give this number but also data from existing accelerators can be taken since these numbers are in good accordance with the state of the art at the moment.
For small power supplies the number is around 80 000 hrs to 100 000 hrs. With the above described system the redundancy shall be increased. For medium and large size power supplies in the range of 1kW – several hundreds of kW the MTBF is app. 40 000 hrs. The aim is to increase the MTBF of 200 000 hrs per small size power supply.

The Mean Time To Failure (MTTF) is the time when the failure in the system will occur. Here the Number Of Power Supplies (NOPS) is taken into account.

$$MTTF = \frac{MTBF}{NOPS}$$

A normal run period for the TESLA operation is assumed 4 weeks. The expected Number Of Failures during a four week = 672 hrs run period is

$$NOF = \frac{672hrs}{MTTF}$$

This number is taken for the dimensioning of the redundancy system. For the case of replacing the magnet in the optic this number shall be at least two times smaller than the amount of replaceable power supplies. When the power supplies have to be exchanged the number of spares have to be higher than the NOF.

## Subsections of TESLA

As shown in Fig.1 TESLA is divided into several subsections which are:

- Injectors
- Damping rings
- Main Linac
- Beam Delivery System
- Beam Extraction Lines
  - Main Extraction Line
  - Fast Emergency Extraction Line
- XFEL
  - Beam transport lines
  - Undulator
  - Intersection of the XFEL

Due to the function of the subsections the energy of the beam and the type of magnet different specifications are given.

Not included in this paper are the power supplies that have been investigated by other members of the collaboration such as:

- Injectors by LAL, Orsay
- Damping rings by INFN, Frascati
- Beam transport line for the X FEL by Bessy, Berlin

## Main Linac

In the main linac superconducting quadrupoles and correctors are installed inside the cryo modules. Up to an energy of 125 GeV every second module will have a quadrupole magnet. Every quadrupole magnet will have a vertical steering coil and every second quadrupole magnet will have a horizontal steering coil. For higher energies every third module contains a quadrupole magnet. Every quadrupole magnet will have a vertical steering coil and every second quadrupole magnet will have a horizontal steering coil.

The number of power supplies for less than 125 GeV incl. spares

| Less than 125 GeV | Current | Voltage | Power incl. losses | Needed power | Quantity |
|---|---|---|---|---|---|
| quadrupoles | 50 A | +/- 10 V | 634 W | 250 W | 400 |
| steerers | +/- 20 A | +/- 10 V | 517 W | 250 W | 630 |

The number of power supplies for more than 125 GeV incl. spares

| More than 125 GeV | Current | Voltage | Power incl. losses | Needed power | Quantity |
|---|---|---|---|---|---|
| quadrupoles | 100 A | +/- 10 V | 1130 W | 500 W | 400 |
| steerers | +/-40 A | +/- 10 V | 490 W | 250 W | 630 |

### Location of the power supplies

For maintenance reason a place that is accessible for repair work in case of failures is the best solution. This location would be inside a service hall. As consequence long cables have to transport the current into the tunnel to the magnets.

The disadvantages are

- high losses on the cables
- high installation cost of cable trays and cables
- large volume required inside the tunnel
- additional fire load inside the tunnel

These disadvantages lead to the solution to install the power supplies into the tunnel near the magnets. Now only short DC and AC cables are necessary. The power supplies will be mounted into 19” electronic racks. The height of a rack is app. 1200 mm. There will be at each klystron station in the tunnel (app. every 48 m) a set of nine electronic racks containing the low level rf system, interlock system, BPMs and the power supplies.

### Redundancy system

According to [2] it is possible to rematch the lattice in case of a trip of one quadrupole. The solution is different in the part of the linac used only for the HEP beam, and the part where HEP and FEL beam is provided at the same time.
For the part used only for HEP beam a missing quadrupole can be corrected with the next five quadrupoles. After six quadrupoles downstream the beam is in the same orbit as before. For the part with HEP beam and FEL beam 14 quadrupoles are necessary to correct the trip of a

magnet. This leads to a high level of redundancy in the machine. In the HEP linac 16.6 % and in the HEP/FEL section 7 % of the power supplies may trip without disturbing the luminosity. With a homogenous trip distribution over the length of the linac theoretically up to 56 trips could be possible.

| | |
|---|---|
| Reliability of quadrupole power supplies | |
| Assumed MTBF of one supply | 200 000 hours |
| Number of power supplies NOPS | 738 |
| MTTF of all power supplies MTBF/NOPS | 200 000 Hours/ 738 = 271 Hours |
| This equals to one failure every | 1.6 weeks |
| The expected failures in one 4 week run period | 2.5 |

| | |
|---|---|
| Reliability of steerer power supplies | |
| Assumed MTBF of one supply | 200 000 hours |
| Number of power supplies NOPS | 1108 |
| MTTF of all power supplies MTBF/NOPS | 200 000 Hours/ 1108 = 180 Hours |
| This equals to 1 failure every | 1.1 weeks |
| The expected failures in one 4 week run period | 3.6 |

Even if the achieved MTBF is only 100 000 hrs it does not endanger the operation with 5 trips per run period.

Cabling

During installation there are three bundles of cables that have to be connected to the power supply rack.

These are

- Input power cables three phase 400 V, app. lengths 3m
  The container will get a central power input. The power supply rack will be connected directly to this input point within the container

- DC cables to the magnets, 2*16 mm² cross section, max. lengths 10 m per power supply.
  The cabling between the power supply and the magnet is rather short. To keep installation time inside the tunnel very short and additionally having a failure proof system, cables with connectors on both sides will be used. The advantage is that these cables can be constructed and tested before bringing them into the tunnel. At the magnet a connector panel will be installed to which the cable will be connected. Non-interchangeable connector will prevent a false connection. Also this interface to the magnet and on the other side to the power supply can be checked outside of the tunnel. When installing the hardware or in case of replacement of some hardware the interconnection can be removed or replace very quickly and failure safe.

- Remote control cables (Ethernet connection), Interlock cable max. lengths 20 m. Here again pre-equipped cables with connectors are used to minimize the installation time and decrease the failure rate.

Power requirement

To determine the power requirement only the consumed power is taken. The superconducting magnets do not have any electrical losses during steady state operation. The losses that occur

are the losses on the cables, in the current feed through and inside the power supply. During ramping (the increase of the current) the magnets have a high voltage drop due to the high inductance. Therefore there is a mismatch of the nominal power of the supply and the actual consumed power.
The consumed power for one side of the linac is 261 kW.
Both sides sum up to 522 kW.

## Quench protection

The electronics to detect a quench in the magnet will be integrated into the power supply. The impedance of the magnet and cable system will be calculated with the given current values and the di/dt values in case of set point changes. A mismatch is assumed as a quench. In addition an over voltage detection will be installed. In case a quench is detected there will be an energy dump into diodes and a resistor inside the power supply.
The main component to be protected is not the magnet but the high temperature super-conducting current feed through. The energy of the magnet has to be dumped within 30 sec in order not to damage this feed through.

## XFEL

The free electron laser XFEL uses synchrotron light for research. The general scheme of the XFEL is shown in Fig. 5. The beam is transported in two beam lines according to the beam energy to the switchyard. Here it is separated into lines each having a SASE undulator. The intersections are the beam lines from the transportation tunnel to the SASE undulators and from the undulators into the dump.

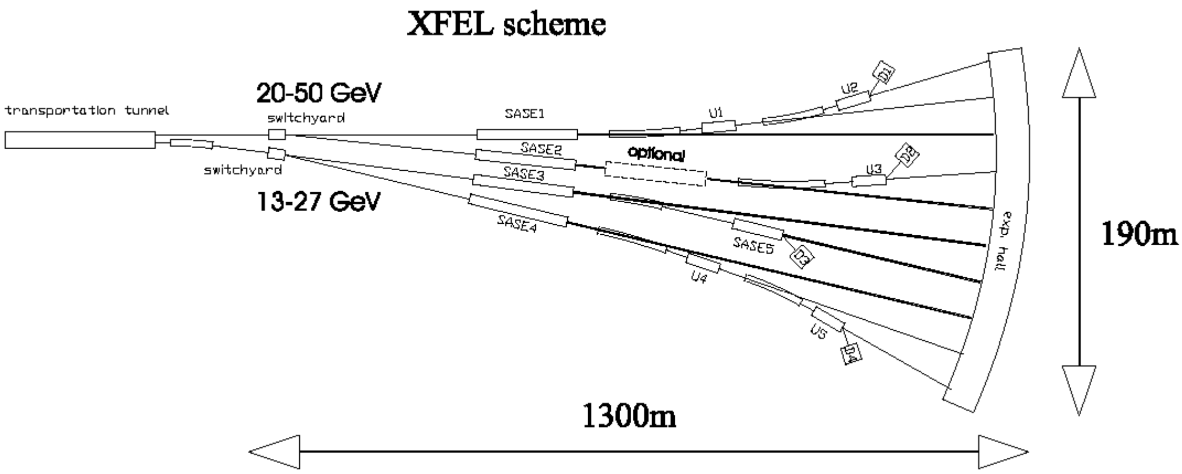


Fig. 5: General scheme of the XFEL

## SASE Undulator

Between the undulator segments most magnets are used for steering and phase shifting. These power supplies are switched mode power supplies with a nominal power of 200 W. A few families of FODO quadrupoles will be installed as well. The general arrangement of the magnets is given in Fig. 6.

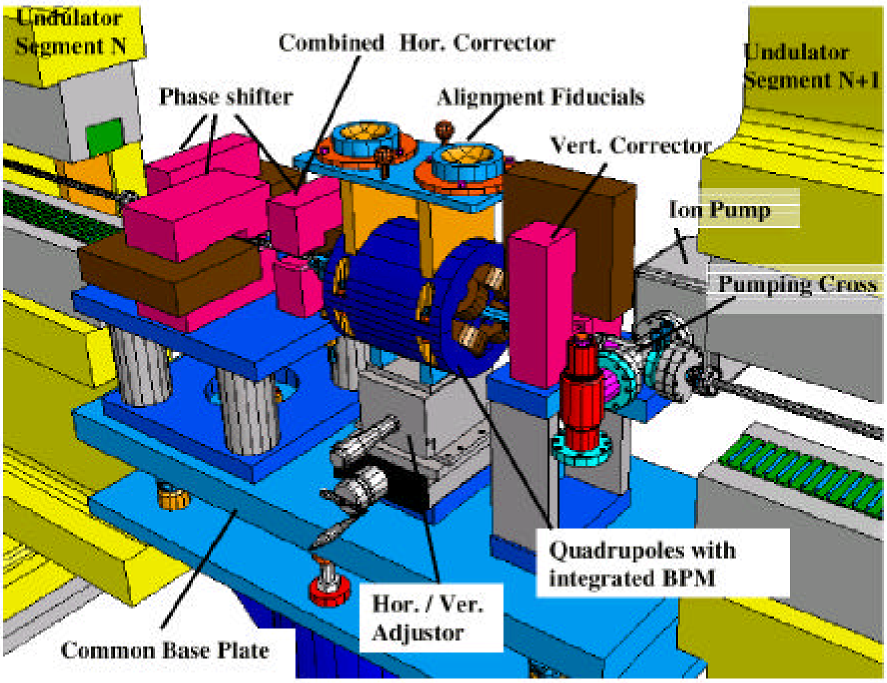


Fig. 6: View of undulator intersection

Types of power supply

Steerer/phase shifter

The same type of power supply as for the steerer in the main linac can be used. The power supplies are bipolar supplies with a current of +/- 20 A and a voltage of +/- 10 V.

Quadrupole supply

The power supplies will be constructed as switched mode supply type buck converter.

Location of the power supplies

The steerer/phase shifter power supplies will be mounted into the electronic racks that are installed along the length of the undulators containing other electronics. These electronic racks are water cooled due to the instrumentation electronics. The amount of dissipated energy from the power supplies is low.

The quadrupole power supplies will have their own electronic racks. Depending on the available space it is possible to install them into the tunnel or into one of the separation halls.

Types of power supplies

| | Current | Voltage | Nominal power | Consumed power | Quantity |
|---|---|---|---|---|---|
| Steerer/ phase shifter | +/- 20 A | +/- 10 V | 250 W | 250 kW | 1200 |
| Type 2 | 200 A | 200 V | 30 kW | 33 kW | 5 |

Redundancy system

For the steerer/phase shifter it is assumed that in case of failure the function is replaced by the optics.

The quadrupole supplies have due to the small number of supplies a good calculated reliability. Since the power supplies are installed in different tunnels they can not be replaced by one single spare supply. The SASE system will therefor use the redundancy system of the intersections as well.

Reliability of quadrupole power supplies

| | |
|---|---|
| Assumed MTBF of one supply | 40 000 hours |
| Number of power supplies NOPS | 5 |
| MTTF of all power supplies MTBF/NOPS | 40 000 Hours/ 5 = 8 000 Hours |
| This equals to one failure every | 47 weeks |
| The expected failures in one 4 week run period | 0.09 |

Reliability of steerer power supplies

| | |
|---|---|
| Assumed MTBF of one supply | 200 000 hours |
| Number of power supplies NOPS | 1200 |
| MTTF of all power supplies MTBF/NOPS | 200 000 Hours/ 1200 = 167 Hours |
| This equals to 1 failure every | 1 weeks |
| The expected failures in one 4 week run period | 4 |

## Intersections of the XFEL

The intersections are different beam lines going to or coming from the undulators. These are the Electron Collimator EC and the Transverse phase space collimator TC, the beam elevation system that elevates the beam from the tunnel level to ground level with the arcs A1, the matching section AM1, AM2. There are two of these lines with different beam energies. The magnet lattice is given in Fig. 7.

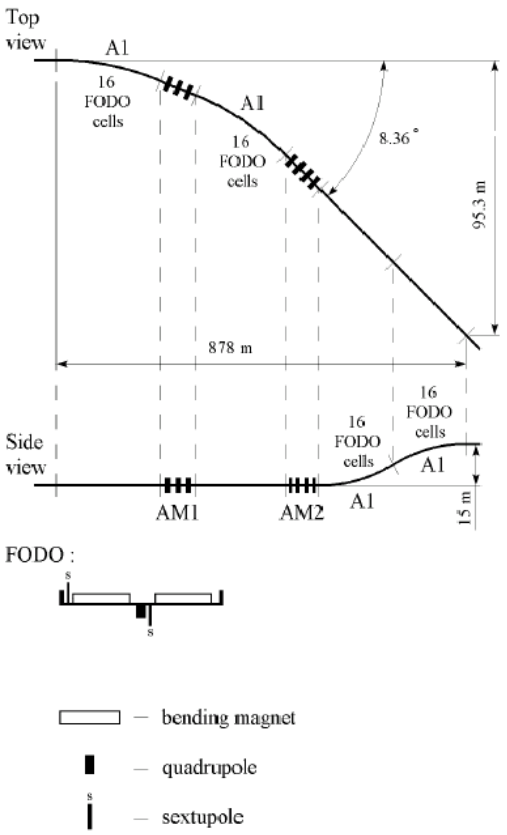


Fig. 7: Magnet lattice of the beam elevation system

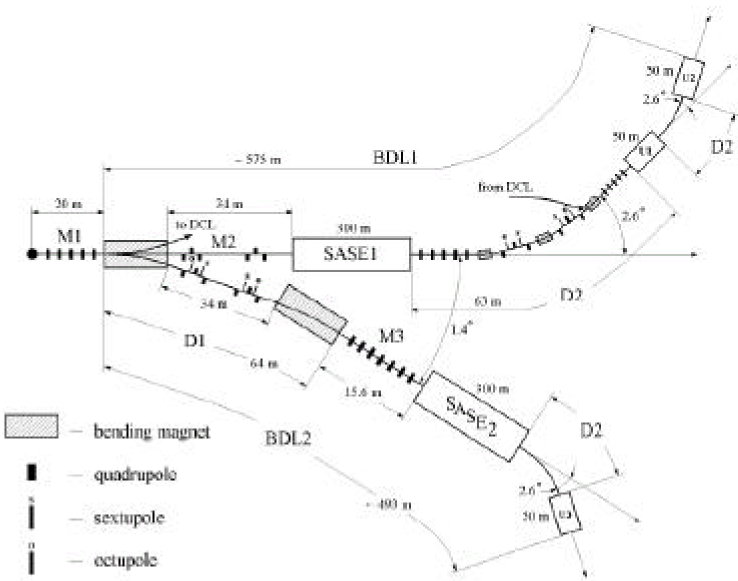


Fig. 8: Magnet lattice of the electron beam distribution system

The electron beam distribution system has the separation sections D1, beam line D2 and the matching sections M1, M2 and M3. The lattice of this section is given in Fig. 8.
The lattice of the diagnostic commissioning line is shown in Fig. 9. Finally the dump lines leading the beam to the dump. In all intersections normal conducting water cooled magnets are installed.

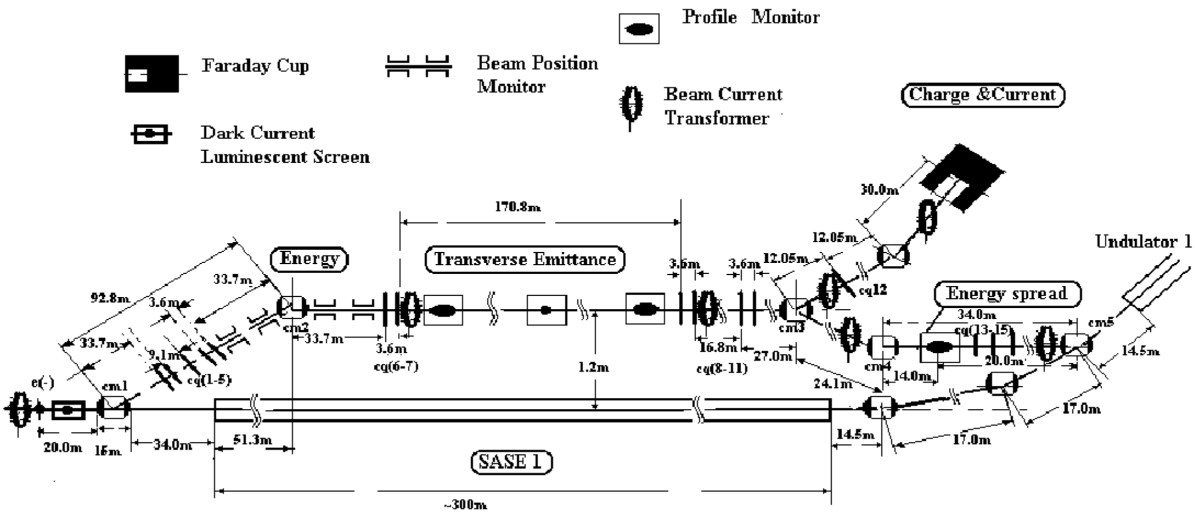


Fig. 9. Lattice of the diagnostic commissioning line

Type of power supplies

The power supplies for the main magnets are in the range from 20 to 500 kW. The medium size power supplies will be of type buck converter. The larger power supplies will be SCR controlled power supplies with passive filters.

The steerers are of the same type of power supply used in the main linac. The power supplies are bipolar supplies with a current of +/- 20 A and a voltage of +/- 10 V.

Power supplies of the intersections of the XFEL incl. redundancy system

| | Current | Voltage | Power | Quantity |
|---|---|---|---|---|
| Type 1 | 100 A | 200 V | 20 kW | 6 |
| Type 2 | 200 A | 200 V | 40 kW | 83 |
| Type 3 | 400 A | 200 V | 80 kW | 88 |
| Type 4 | 600 A | 200 V | 120 kW | 8 |
| Type 10 | 500 A | 1000 V | 500 kW | 6 |
| Type 11 | 600 A | 500 V | 300 kW | 2 |
| Type 12 | 720 A | 100 V | 72 kW | 12 |
| Type 13 | 1200 | 60 V | 72 kW | 7 |
| Type 14 | 1700 A | 150 V | 255 kW | 8 |
| Steerer | +/- 20 A | +/- 10 V | 200 W | 120 |

Location of the supplies

The switched mode power supplies will be located inside the tunnel to have low cabling and installation cost.

The SCR controlled power supplies will be positioned inside the separation halls and in the dump halls. In the separation halls the tunnel splits into two, from here the current is transported via cables to the magnets. The distances to the magnet is short (max. 100 m) therefore the losses on the cables are low.

Redundancy system

Since the magnets are installed in different tunnels the redundancy system has to be distributed as well. There are five sections. Four of them are fed from the dump halls. From here all supplies of the ADL and the D2 sections and in one hall the DCL are fed. The fifth zone is the beginning of the separation zone. From here the power supplies of the EC, TC A1, D1 and M are fed. As described above the power supplies are disconnected via switches from the magnet and the spare power supply is switched over.
The reliability is calculated for these five sections.

Overall Reliability

| | |
|---|---|
| Assumed MTBF of one supply | 40 000 hours |
| Number of power supplies NOPS | 209 |
| MTTF of all power supplies MTBF/NOPS | 40 000 Hours/ 209 = 191 Hours |
| This equals to one failure every | 1.1 weeks |
| The expected failures in one 4 week run period | 3.5 |

Section 1 feeding ADL, 2*D2, DCL

| | |
|---|---|
| Assumed MTBF of one supply | 40 000 hours |
| Number of power supplies NOPS | 56 |
| MTTF of all power supplies MTBF/NOPS | 40 000 Hours/ 56 = 714 Hours |
| This equals to one failure every | 4,3 weeks |
| The expected failures in one 4 week run period | 0.94 |

Section 2,3 feeding each ADL, D2

| | |
|---|---|
| Assumed MTBF of one supply | 40 000 hours |
| Number of power supplies NOPS | 23 |
| MTTF of all power supplies MTBF/NOPS | 40 000 Hours/ 23 = 1739 Hours |
| This equals to one failure every | 10.4 weeks |
| The expected failures in one 4 week run period | 0.38 |

Section 4 feeding ADL, 2*D2

| | |
|---|---|
| Assumed MTBF of one supply | 40 000 hours |
| Number of power supplies NOPS | 38 |
| MTTF of all power supplies MTBF/NOPS | 40 000 Hours/ 38 = 1052 Hours |
| This equals to one failure every | 6,26 weeks |
| The expected failures in one 4 week run period | 0.64 |

Section 5 feeding EC, TC, D1, A1, M

| | |
|---|---|
| Assumed MTBF of one supply | 40 000 hours |
| Number of power supplies NOPS | 69 |
| MTTF of all power supplies MTBF/NOPS | 40 000 Hours/ 69 = 579 Hours |
| This equals to one failure every | 3.4 weeks |
| The expected failures in one 4 week run period | 1.16 |

There is one trip expected per run 4 week period and section. With the redundancy system this trip can be handled. Since the power supplies are installed in the halls they are accessible and can be repaired at any time. This increases the safety.

Power requirements

Power requirements of the intersection of the XFEL

| | |
|---|---|
| Power of magnets | 3472 kW |
| Losses in main power supplies | 100 kW |
| Losses on cable | 30 kW |
| Power for cooling | 270 kW |
| Losses of steerers | 30,0 kW |
| | |
| Sum | 3902 kW |

## Beam delivery system

The last 1.7 km before the interaction point is called the <u>B</u>eam <u>D</u>elivery <u>S</u>ystem. Here there is no further acceleration but the beam is transported to the interaction point. The magnets are normal conducting magnets with medium power below 90 kW. These magnets are water cooled. The lattice is shown in Fig. 10. Each quadrupole magnet has a steering magnet in horizontal and vertical direction.

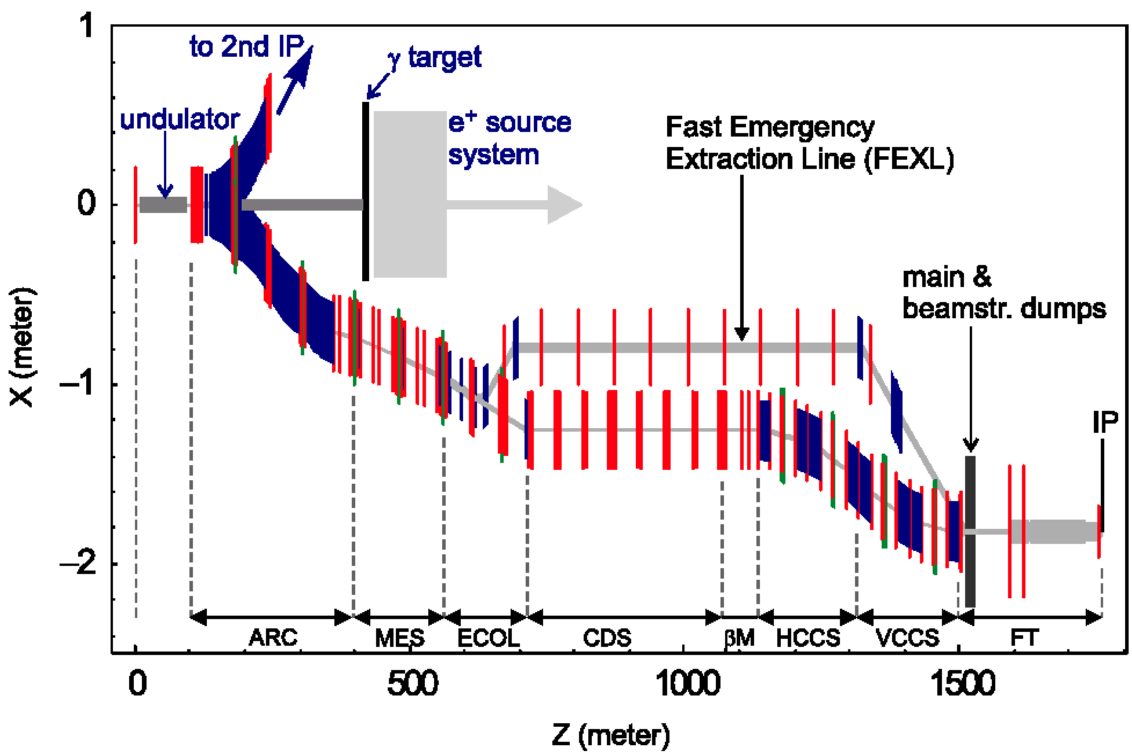


Fig. 10: Overview of the magnet lattice of the Beam delivery system

Type of power supplies

Main magnets

The magnets have medium power. The power supplies will be built as buck converter.

Steering magnets

The same type of power supply as in the main linac is used. The power supplies are bipolar supplies with a current of +/- 20 A and a voltage of +/- 10 V.

Power supplies of the BDS incl. redundancy system

| | Current | Voltage | Power | Quantity |
|---|---|---|---|---|
| Type 1 | 100 A | 200 V | 20 kW | 44 |
| Type 2 | 200 A | 200 V | 40 kW | 46 |
| Type 3 | 400 A | 200 V | 80 kW | 8 |
| Type 4 | 450 A | 250 V | 112,5 kW | 16 |
| steerer | +/- 20 A | +/- 10 V | 200 W | 400 |

Location of the power supplies

The power supplies will be installed into the tunnel. The cabling would be to expensive when putting the power supplies into the dump halls. The power supplies will be fed from the 400 V mains that are installed in the tunnel.

Redundancy system

In the BDS system all power supplies have to work without failures during operation. Therefore spare power supplies will be installed in service halls. The power supplies are divided into three groups.

These groups are 100 A, 200A and 450 A corresponding to the different types of power supplies. For each of these groups a spare cable is installed over the entire length of the BDS system into the tunnel.

Reliability for one side of the BDS

Main magnets

| | |
|---|---|
| Assumed MTBF of one supply | 40 000 hours |
| Number of power supplies NOPS | 53 |
| MTTF of all power supplies MTBF/NOPS | 40 000 hours/ 53 = 754,7 hours |
| This equals to | 4.5 weeks |
| The expected failures in one 4 week run period | 0.88 |

During a run time of four weeks one power supply is assumed to fail. This failure can be handled with the redundancy system.

Steerer

| | |
|---|---|
| Assumed MTBF of one supply | 200 000 hours |
| Number of power supplies NOPS | 200 |
| MTTF of all power supplies MTBF/NOPS | 200 000 hours/ 200 = 1 000 hours |
| This equals to | 6 weeks |
| The expected failures in one 4 week run period | 0.67 |

Cabling

When looking at the low failure rate no special fast connectors for the power cabling will be introduced but the cables will be connected with screwed cable lugs to the mains and the magnets. The interlock and remote control cables will be connected via connectors.
The interlock cabling will be connected via plugs.

Power requirements

Power requirements of the BDS

| | |
|---|---|
| Power of BDS one side | 498,7 kW |
| Losses in main power supplies one side | 49,9 kW |
| Losses on cable one side | 19,8 kW |
| Power for cooling one side | 81,0 kW |
| Losses of correctors one side | 30,0 kW |
| | |
| Sum one side | 679,4 kW |
| | |
| both sides | 1358,9 kW |

## Extraction Lines

In the area of the Beam Delivery System two extraction lines are installed at each side of the interaction point. These are the Main Extraction Line (MEL) and the Fast Emergency eXtraction Line (FEXL). The MEL is transporting the beam from the interaction point to the dump hall. The FEXL is used for the commissioning of TESLA and later in case of a problem with the beam from the linac. The beam is bypassed at this area and transported directly to the beam in order not to damage any equipment.

Types of power supplies

Main magnets

In the extraction line most of the magnet families need high power. These power supplies are built as SCR controlled power supplies with passive filter.

Steering magnets

The same type of power supply as for the steerer in the main linac can be used. The power supplies are bipolar supplies with a current of +/- 20 A and a voltage of +/- 10 V.

The power supplies of the extraction lines incl. redundancy system:

| | Current | Voltage | Power | Quantity |
|---|---|---|---|---|
| Type 1 | 100 A | 200 V | 20 kW | 4 |
| Type 5 | 300 A | 700 V | 210 kW | 2 |
| Type 15 | 1500 A | 200 V | 300 kW | 10 |
| Type 16 | 2000 A | 400 V | 800 kW | 8 |
| Type 17 | 500 A | 1200 V | 600 kW | 4 |
| Type 18 | 4000 A | 60 V | 240 kW | 6 |
| Steerer | +/-25 A | +/- 10 V | 200 W | 72 |

Location of the power supplies

The large power supplies will be installed into the dump hall. The magnets will be connected via cables. The few switched mode supplies will be installed into the tunnel as mentioned for the BDS. The electrical power supply will be from the dump halls.

Redundancy system

It is obvious that in the extraction line all power supplies have to work without failures during operation to get the beam into the dump.
The magnets will be connected via high current switches to the power supplies. In case of a trip the magnet will be connected to a spare supply. There will be a redundancy system for each side. Since both lines do not have many supplies they will use the same redundancy system.

| | |
|---|---|
| Assumed MTBF of one supply | 40 000 hours |
| Number of power supplies NOPS | 26 |
| Assumed TBF of all power supplies MTBF/NOPS | 40 000 hours/ 26 = 1538 hours |
| This equals to | 9.2 weeks |
| The expected failures in one 4 week run period | 0.43 |

During a run time of four weeks one power supply is assumed to fail. This failure can be handled with the redundancy system. Since the groups of power supplies that are replaced by the spare power supply are not large even more failures can be handled.

Steerer

| | |
|---|---|
| Assumed MTBF of one supply | 200 000 hours |
| Number of power supplies NOPS | 36 |
| MTTF of all power supplies MTBF/NOPS | 200 000 hours/ 36 = 5 555 hours |
| This equals to | 33 weeks |
| The expected failures in one 4 week run period | 0.12 |

Cabling

When looking at the low failure rate no special fast connectors for the power cabling will be introduced but the cables will be connected with screwed cable lugs to the mains and the magnets. The interlock and remote control cables will be connected via connectors.

Power requirements

It is assumed that a three phase power line is installed inside the tunnel. The large power supplies need a 400 V distribution inside the dump hall. The power requirements are:

Power requirements of the Extraction Lines

| | |
|---|---|
| power of Extraction lines one side | 2753,1 kW |
| Losses in main power supplies one side | 438,5 kW |
| Losses on cable one side | 170 kW |
| Losses in Recooling one side | 15,0 kW |
| Losses of correctors one side | 18,0 kW |
| | |
| Sum one side | 3380,9 kW |
| both sides | 6761,8 kW |

## Summary

There is a large number of different power supplies that are needed for TESLA. The given current, voltage and power ratios of the magnets are not exceeding the range of conventional techniques. For a smooth operation of the accelerator these power supplies will have to work very reliably. It is shown that with a high redundant design of the power supply the failure rate can be reduced. The still possible failures of the power supplies have to be handled with a redundancy system. This can be a change in the beam optics as is done for the main linac and for the steering power supplies, or as a replacement of the power supplies. A spare power supply is connected to the magnet of the tripped supply via contactors or high current switches. The calculated probability of the failures show that a smooth operation is possible.

The total number of power supplies is

| | Current | Voltage | Power | Quantity |
|---|---|---|---|---|
| Type 1 | 100 A | 200 V | 20 kW | 54 |
| Type 2 | 200 A | 200 V | 40 kW | 134 |
| Type 3 | 400 A | 200 V | 80 kW | 96 |
| Type 4 | 600 A | 200 V | 120 kW | 8 |
| Type 5 | 450 A | 250 V | 112.5 kW | 16 |
| Type 6 | 300 A | 700 V | 210 kW | 2 |
| Type 10 | 500 A | 1000 V | 500 kW | 6 |
| Type 11 | 600 A | 500 V | 300 kW | 2 |
| Type 12 | 720 A | 100 V | 72 kW | 12 |
| Type 13 | 1200 A | 60 V | 72 kW | 7 |
| Type 14 | 1700 A | 150 V | 255 kW | 8 |
| Type 15 | 1500 A | 200 V | 300 kW | 10 |
| Type 16 | 2000 A | 400 V | 800 kW | 8 |
| Type 17 | 500 A | 1200 V | 600 kW | 4 |
| Type 18 | 4000 A | 60 V | 240 kW | 6 |
| Steerer | +/-20 A | +/- 10 V | 200 W | 2422 |
| Steerer | +/-40 A | +/- 10 V | 400 W | 630 |
| Quadrupole Linac | 100 A | +/- 10 V | 1 kW | 400 |
| Quadrupole Linac | 50 A | +/- 10 V | 500 W | 400 |


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[3]Ciemat, Spain, DESIGN AND FABRICATION STUDY ON THE TESLA500 SUPERCONDUCTING MAGNET PACKAGE, 2000

[4] Rittal, Gesamtkonzept Kühlung, Internal paper

# Appendix: Excerpt from DESIGN AND FABRICATION STUDY ON THE TESLA500 SUPERCONDUCTING MAGNET PACKAGE, 2000

**5.- The Power Supplies : General Considerations**

The superconducting magnets for the TESLA500 project, require a number of power supplies with specific characteristics which must be defined according to the following relevant issues:

- System reliability
- Environmental radiation level
- High efficiency and low thermal losses
- High precision
- Modularity and interchange capability
- Ability to absorb the stored energy in the magnets
- Good system maintenance

There are four types of magnets to be fed with the power supplies proposed in this report, according to the following classification:

Table 5.1.- Magnet types for TESLA 500

| TYPE OF MAGNET | NOMINAL CURRENT (A) | MAXIMUM VOLTAGE (V) | MAGNET SELF-INDUCTANCE(H) | CURRENT ACCURACY(mA) |
|---|---|---|---|---|
| Bipolar (Dipole) | 40 | +/- 10 | 0.029 | 4 |
| Bipolar (Dipole) | 20 | +/- 10 | 0.029 | 2 |
| Unipolar(Quad.) | 100 | +10 | 2.3 | 10 |
| Unipolar(Quad.) | 50 | +10 | 2.3 | 5 |

Present report details functional specifications for the power supplies for the magnets described in table 5.1.

**5.1.- General Description of the System**

Every Power Supply (PS) will be fed from 400V /50 Hz 3-phase a.c current, which will be connected to each cabinet of the converters through a 3-phase protection switchgear.

Inside each cabinet there will be placed three power supplies: one 100 A unipolar unit, a 40 A bipolar unit and finally a 20 A bipolar supply or, alternatively any other combination of power supplies with the same number of units.

Grid voltage will be rectified and regulated to achieve a 400 V d.c. stabilised voltage with low ripple. This conversion will be redundant by means of converters as described in 5.2.1.1. The three power supplies in each cabinet will be fed from this d.c. current. This d.c. voltage will be galvanically isolated and regulated with d.c./d.c. converters as described in 5.2.2.1.

Output voltage for every power supply can be regulated in amplitude using a PWM technique from a reference value given by the control system for each power supply, which will also provide a low ripple output ( less than 200 mV pp) in all the output range. The d.c./d.c. converters can work in parallel, thus automatically shearing the current.

For the unipolar coils, there will be series connected devices to provide a negative voltage to discharge the magnets. These devices will consist of a number of diodes also connected in series with a discharging resistor in parallel with the full arrangement. This will increase the safety of the whole system. The complete device can be short-circuited by means of relays, so that under nominal operation they will be short-circuited and when energy absorption is required, the relay will be opened, thus providing the necessary voltage drop. As a safety conditions these relays will be duplicated.

For bipolar magnets, d.c./d.c. converters will also be used, which will be identical to those for the unipolar magnets. Along with these converters there will be a further MOSFET H bridge stage to allow the commutation of the output polarity to provide positive and negative voltages and currents. To absorb the discharging energy of the magnets, the current flowing path will be established though the inverse diodes of the H bridge, towards the d.c. side of the this stage, which will include a capacitor to absorb part of the energy increasing its voltage. To control this voltage there will be placed a discharging resistor with a control MOSFET.

This MOSFET can be switched ON or OFF. If the voltage across the capacitor is higher than the reference value plus a margin (K1), the MOSFET will be switched ON, the resistor is connected and there will be provided an alternative path to discharge the energy. When the voltage is reduced to the reference value plus another margin (K2, K2<K1), the MOSFET will be switched OFF and the discharging energy will increment again the capacitor voltage. This cycle will repeat allowing the control of the d.c. side voltage during recovery operation.

For safety reasons it will be also included a voltage limiter at 16 V using series connected diodes and a low value limiting resistor.

Control unit for every power supply will include a DSP and a microprocessor plus the necessary analogue circuitry. This unit receives the theoretical current reference value from the Remote Control Centre and establishes the theoretical output voltage for the d.c./d.c. converter of the PS. Actual value of the output current is measured with a precision shunt and then amplified to the required levels. To achieve the necessary accuracy, the temperature of the shunt and amplifiers is kept constant using Peltier cells at 35º C +/- 1ºC. The control compares the reference and the actual values for the current and varies the output voltage to maintain the specified value within the required accuracy.

Communications between the cabinet and the Remote Control Centre is achieved with a PLC S-7 placed inside each cabinet. This PLC allows the information transmission about status, actual current and voltage levels in each of the three magnets fed from each cabinet, regulation parameters, etc.

### 5.2.- Description of Each Module

#### 5.2.1.- Cabinet

Dimensions of the cabinets are: Height = 1100 mm, Width = 600 mm, Depth = 800 mm.
Accessibility to the cabinet will be through the frontal side. Every Cabinet will house the following common elements:

##### 5.2.1.1.- Input Rectifier Stage

Two units in each cabinet so that, even in the case one of them failures, the system will continue to operate. Main features of these units will be:

- Plug-in connections with appropriate connectors
- Extractable and insertable during operation
- Input voltage: 400 V rms +/- 5%, three phase, 50 Hz +/- 1%. Short Circuit Current<= 10 kA
- Output Voltage: 400 V d.c ( regulated within 1% accuracy). Output ripple< 0.5%. Current limitation. Regulation Curve: -IR for parallel operation. Output current limitation.
- Output provided with coupling diodes in both polarities
- Input swithchgear and connection relay with limitation resistor to reduce inrush current
- Steady-State operational current 5 A ( 2000 W)
- Dimensions per module: Height = 2U(90 mm), Width = 220 mm, Depth = 300 mm. Weigh = 2 K
- Alarms/ signals: Module Failure/ Module on Service

##### 5.2.1.2.- Central Control System Interface

This interfacing will be performed with PLC S-7 or equivalent, allowing communications of the PS located in the cabinet and the rest of components with the Control System via optic-fibre.

Signals for communication are:

- a.c./d.c. module status (Failure/Operation).
- Refrigeration status (Failure/Operation).

- Status of each PS located in the cabinet.
- Input Current reference values for each PS located in the cabinet
- Input Regulation parameters for each PS located in the cabinet
- Output of the actual current values for each PS located in the cabinet
- Output of the output voltage values for each PS located in the cabinet
- Input for commands for each PS located in the cabinet
- Output for quench Status for each PS in the cabinet.

**5.2.2.- PS Components for Unipolar Magnets**

**5.2.2.1.- d.c./d.c. Converter**

Depending on the required current each PS will include the necessary number of single modules ( see paragraph 5.4). Each d.c./d.c. module has the following characteristics:

- Input voltage: 400 V from the a.c./d.c. stage
- Input relay with a resistor for inrush current limitation
- Plug-in connection ( extractable and insertable in operation)
- Input filter
- MOSFET H-Bridge working at high constant frequency with PWM and double modulation (+V,0-V)
- Output filter to reduce voltage ripple down to 200mV pk-pk
- Output voltage regulation between 0 and 10 V
- Maximum steady-state current 25 A in all the voltage range
- Output voltage ripple less than 200 mV pk-pk
- Input/Output isolation = 1000 V a.c. 50 Hz during 60 s
- Output Freewheeling diode
- PWM Regulation with output voltage control. Load equalisation for parallel operation (-IR performance). Current limitation to 27 A and internal failure detection
- Output voltage as a function of the assignated value from the control module
- Output voltage accuracy: better than +/- 0.05 V in steady conditions
- Dimensions: Height = 6U, Width = 12 TE( 7U in 600 mm), Depth =300 mm. Weight = 2.5 K

**5.2.2.2.- Negative Voltage Switch (NVS)**

This switch allows the straight connection of the d.c./d.c. module and the load, and also the connection through diodes providing a negative voltage drop and a parallel resistor in parallel with it as a safety factor.

Both, the series arrangement of diodes as well as the resistor, are designed to absorb all the energy stored in the corresponding magnet. This is the reason why there are two different types of these modules ( for 100 A and 50 A).

The seven diodes in series allow a voltage drop of 6.4V (0.8V per diode plus the freewheeling diode). The resistor will have the necessary value for a voltage drop of 100 V at nominal current and will allow to dissipate all the stored energy in the magnet without heating up to more than 160ºC. When the voltage across this resistor is higher than 16 V, the “ diode failure” alarm will be on.

There will be one NVS per unipolar power supply.

**5.2.2.3.- Regulation**

The regulation module will contain:

- A precision shunt for the measurement of the output actual current.
- Amplification circuitry for the shunt signal.
- Power supply ( duplicated).
- Communication circuits with the S-7 system for cabinet monitoring.
- Current control circuits, commanding the dc/dc stage.
- Temperature control of the current measuring devices with Peltier cells.
- Regulation module receiving the reference output current value from the remote control system through the PLC, S-7 placed in the cabinet.
- It also receives the actual current value through the shunt and associated amplifier.
- It compares both values and establishes the suitable voltage at the dc/dc stages already described.

- It includes a 22 bit DAC conversion.

### 5.2.3.- Bipolar Power Supplies Elements

dc/dc specific components are identical to those described in 5.2.2.1 for the unipolar magnets. To inverse the polarity in the output current there will also be an H bridge inverter stage using MOSFET ( dc/ac).

#### 5.2.3.1.- H-Bridge (dc/ac)

This unit allows to switch the magnet current polarity. It is based on a four MOSFET bridge with the necessary protections. Polarity commutation takes place from the control system as a function of the reference current polarity (+/-).

Inverse diodes associated to MOSFET will allow the current flow for each sense through the dc input in that stage, which includes a capacitor to store the energy in the magnet, thus increasing the voltage across its terminals. To avoid overvoltages, there will also be a Crowbar (CRW) device which will be described later on.

The unit will be divided in 20 A modules, able to be connected in parallel. It also includes a relay with an inrush current limitation resistor. These modules will also be able to be plugged and unplugged during operation.

Module dimensions are: Height 3U, width 12 TE and depth 300 mm. Estimated weight is 2 Kg.

#### 5.2.3.2.- Crowbar (CRW)

To absorb the energy stored in the correspondent magnet, avoiding dangerous overvoltages in the dc side, a crowbar is included as it was already mentioned. It consists of a resistor and a MOSFET operating as a static swtich. The control of this MOSFET is established according to the reference value given by the voltage control system.

If the actual voltage is higher than the assigned voltage to the MOSFET in a preselected value K1, the MOSFET will switch to the ON state, the resistor is connected providing a discharging path for the magnet current. Under these circumstances, dc current will decrease until it achieves another preselected value K2 ( lower than K1) and the MOSFET will switch to the OFF state disconnecting the resistor.

This operation will repeat the necessary number of times until all the stored energy in the magnet is absorbed. As and additional safety element a redundant crowbar will be placed in parallel.

This second crowbar will include two diodes with a voltage threshold of 16 V. In series with this diodes a low value resistor will be connected for limiting considerations.

If this threshold is achieved as a main crowbar failures, the correspondent alarm will be fired.

#### 5.2.3.3.- Regulation

Regulation of this power supply is similar to the one described in 5.2.2.3, being bipolar in this case.

### 5.2.4.- Environment

These power supplies must operate in a high radiation environment. For this reason it is foreseen to use standard electronics with professional quality. To protect the circuits from radiation, 12 mm thick lead screen will be placed in the lateral sides of the cabinets, which will be located inside the steel walls of the cabinet. Refrigeration is done by means of forced air circulation with fans.

This offer DO NOT INCLUDE the water-air heat intercooler. An additional air-air refrigeration system is included as a safety factor.

### 5.3.- Technical Characteristics Summary

Table 5.2.- Technical Characteristics

| Part nº | Item | Nominal Val. | Maximum Val. | Minimum Val. |
|---|---|---|---|---|
| **1** | **a.c. supply** | | | |
| 1.1 | Phase to phase r.m.s.Voltage | 400 V | + 5% | -5% |
| 1.2 | Number of Phases | 3 | | |
| 1.3 | Frequency | 50Hz | +1% | -1% |
| 1.4 | Shortcircuit Current | | 10 KA | |
| 1.5 | Power Factor | 0.93 | | |
| **2** | **a.c./d.c. supply** | | | |
| 2.1 | Supply | See point 1 | | |
| 2.2 | d.c. Output Voltage | 400 V | +1% | -1% |
| 2.3 | Output Voltage Ripple | | 0.5% | |
| 2.4 | Input-Out Isolation | NO | | |
| 2.5 | Parallel Coupling | YES (-I*R) | | |
| 2.6 | Inrush Current | | <1.1* I max.nom. | |
| 2.7 | Output current per Module | 5A | 6A | 0A |
| 2.8 | Output Current Limitation | YES | | |
| 2.9 | Input-Output Isolation | NO | | |
| 2.10 | Plug-In | YES | | |
| 2.11 | Efficiency | | 93% | |
| **3** | **d.c. Converter** | | | |
| 3.1 | Supply | See point 2 | | |
| 3.2 | Inrush Current | | 1.1* I max.nom. | |
| 3.3 | Output Voltage | | 10 V dc | 0 V dc |
| 3.4 | Output Voltage Ripple | | 200 mV pk-pk | |
| 3.5 | Output Current per Module | 25 A | 27A | 0A |
| 3.6 | Freewheling diode | YES | | |
| 3.7 | Output Voltage Static Stability | | +0.05 V | -0.05 V |
| 3.8 | Current Limitation | YES | 27 A | |
| 3.9 | Type of Conmutation | Fixed Frequency | | |
| 3.10 | Type of Regulation | PWM | | |
| 3.11 | Internal Module Failure Detection | YES | Selective | V>,ºC,>I,V< |
| 3.12 | Input-Output Isolation | YES | | 1KV, 50 Hz, 60 s |
| 3.13 | Efficiency | | 90% | |
| **4** | **Negative Voltage Switch 100A** | | | |
| 4.1 | Negative Voltage | -6.4 V | | |
| 4.2 | Number of Diodes in Series | 7 | | |
| 4.3 | Nominal Current | 100 A | 110 A | |
| 4.4 | Energy | | 15 KJ | |
| 4.5 | Parallel Resistor | 1 Ohm | 100 V | 500 W |
| **5** | **Negative Voltage Switch 50 A** | | | |
| 5.1 | Negative Voltage | -6.4 V | | |
| 5.2 | Number of Diodes in Series | 7 | | |
| 5.3 | Nominal Current | 50 A | 55 A | |
| 5.4 | Energy | | 4 KJ | |
| 5.5 | Parallel Resistor | 2 Ohm | 100 V | 200 W |
| **6** | **d.c./a.c. Inverter** | | | |
| 6.1 | Supply | See point 3 | | |
| 6.2 | Maximum Inrush Current | | 1.1*I max. nom. | |
| 6.3 | Current per Module | 20 A | 22 A | |

| Part nº | Item | Nominal Val. | Maximum Val. | Minimum Val. |
|---|---|---|---|---|
| 6.4 | Output Voltage | | +10 V | -10 V |
| 6.5 | Efficiency | | 96% | |
| 6.6 | d.c. Input Capacitor | 15 ? F | 30 V | |
| 6.7 | Input-Output Isolation | NO | | |
| **7** | **Crowbar 40 A** | | | |
| 7.1 | Current | 40 A | 50 A | |
| 7.2 | Discharging Resistor | | 0.1 Ohm | 100 W |
| 7.3 | Threshold connection voltage | | +0.3 V(incremental) | |
| 7.4 | Threshold discon. voltage | | +0.1V (incremental) | |
| 7.5 | Safety Threshold | | 16 V | |
| **8** | **Crowbar 20 A** | | | |
| 8.1 | Current | 20 A | 25 A | |
| 8.2 | Discharging Resistor | | 0.1 Ohm | 60 W |
| 8.3 | Threshold connection voltage | | +0.3 V(incremental) | |
| 8.4 | Threshold discon. voltage | | +0.1V (incremental) | |
| 8.5 | Safety Threshold | | 16 V | |
| **9** | **Unipolar Power Supplies 100 A** | | | |
| 9.1 | Voltage | | 10 V d.c. | -6.4 V/-100V |
| 9.2 | Current | | 100 A | |
| 9.3 | Current reproducibility | | | 5 mA |
| 9.4 | Current Accuracy | | | 10 mA |
| 9.5 | Current Ripple | | +10 mA | -10 mA |
| 9.6 | Voltage Ripple | | 200 mV pk-pk | |
| 9.7 | Operational Temperature | | 40º C | 20º C |
| 9.8 | Preparation Time | | 1 hour | |
| 9.9 | Quench Detection | >10 V,>dU/dt | U-L*di/dt | |
| 9.10 | Internal Interlocks | >ºC; Io ;>Vo | Quench Detection | |
| 9.11 | Beam Inhibit Signal | Relays Contacts | Opens 2s in case of | Failure or Turn off |
| 9.12 | Commands | Switch | On/Off | |
| 9.13 | Main Contact | On/Off | | |
| 9.14 | Actual Current | YES | | |
| 9.15 | >º C | Alarm | | |
| 9.16 | Error Message | YES | | |
| 9.17 | Inductance | 2.3 H | | |
| **10** | **Unipolar Power Supplies 50 A** | | | |
| 10.1 | Voltage | | 10 V d.c. | -6.4 V/-100V |
| 10.2 | Current | | 50 A | |
| 10.3 | Current reproducibility | | | 2.5 mA |
| 10.4 | Current Accuracy | | | 5 mA |
| 10.5 | Current Ripple | | +5 mA | -5 mA |
| 10.6 | Voltage Ripple | | 200 mV pk-pk | |
| 10.7 | Operational Temperature | | 40º C | 20º C |
| 10.8 | Preparation Time | | 1 hour | |
| 10.9 | Quench Detection | >10 V,>dU/dt | U-L*di/dt | |
| 10.10 | Internal Interlocks | >ºC; Io ;>Vo | Quench Detection | |
| 10.11 | Beam Inhibit Signal | Relays Contacts | Opens 2s in case of | Failure or Turn off |
| 10.12 | Commands | Switch | On/Off | |
| 10.13 | Main Contact | On/Off | | |
| 10.14 | Actual Current | YES | | |
| 10.15 | >º C | Alarm | | |
| 10.16 | Error Message | YES | | |
| 10.17 | Inductance | 2.3 H | | |

| Part nº | Item | Nominal Val. | Maximum Val. | Minimum Val. |
|---|---|---|---|---|
| **11** | **Bipolar Power Supplies 40 A** | | | |
| 11.1 | Voltage | | +/-10 V d.c. | -6.4 V/-100V |
| 11.2 | Current | | +/- 40 A | |
| 11.3 | Current reproducibility | | | 2 mA |
| 11.4 | Current Accuracy | | | 4 mA |
| 11.5 | Current Ripple | | +4 mA | -4 mA |
| 11.6 | Voltage Ripple | | 200 mV pk-pk | |
| 11.7 | Operational Temperature | | 40º C | 20º C |
| 11.8 | Preparation Time | | 1 hour | |
| 11.9 | Quench Detection | >10 V,>dU/dt | U-L*di/dt | |
| 11.10 | Internal Interlocks | >ºC; Io ;>Vo | Quench Detection | |
| 11.11 | Beam Inhibit Signal | Relays Contacts | Opens 2s in case of | Failure or Turn off |
| 11.12 | Commands | Switch | On/Off | |
| 11.13 | Main Contact | On/Off | | |
| 11.14 | Actual Current | YES | | |
| 11.15 | >º C | Alarm | | |
| 11.16 | Error Message | YES | | |
| 11.17 | Inductance | 29 mH | | |
| **12** | **Bipolar Power Supplies 20 A** | | | |
| 12.1 | Voltage | | +/-10 V d.c. | -6.4 V/-100V |
| 12.2 | Current | | +/- 20 A | |
| 12.3 | Current reproducibility | | | 1 mA |
| 12.4 | Current Accuracy | | | 2 mA |
| 12.5 | Current Ripple | | +2 mA | -2 mA |
| 12.6 | Voltage Ripple | | 200 mV pk-pk | |
| 12.7 | Operational Temperature | | 40º C | 20º C |
| 12.8 | Preparation Time | | 1 hour | |
| 12.9 | Quench Detection | >10 V,>dU/dt | U-L*di/dt | |
| 12.10 | Internal Interlocks | >ºC; Io ;>Vo | Quench Detection | |
| 12.11 | Beam Inhibit Signal | Relays Contacts | Opens 2s in case of | Failure or Turn off |
| 12.12 | Commands | Switch | On/Off | |
| 12.13 | Main Contact | On/Off | | |
| 12.14 | Actual Current | YES | | |
| 12.15 | >º C | Alarm | | |
| 12.16 | Error Message | YES | | |
| 12.17 | Inductance | 29mH | | |

### 5.4.-System Composition

Table 5.3.- System Composition

| Cabinet Configuration | ac/dc5A 400V Input Module | dc/dc 25A Modules | NVS Modules | dc/ac 20A Modules | Crowbar | PLC | Regulation Unipolar Module | Regulation Bipolar Module |
|---|---|---|---|---|---|---|---|---|
| 1xPs 100A+10V<br>1xPs 40A +-10V<br>1xPS 20A+-10V | 2 | 11 | 1x100A<br>1x50A | 5 | 1x40A<br>1x20A | 1 | 1x100A<br>1x50A | 1x40A<br>1x20A |
| | | | | | | | | |
| **Configuration PowerSupply** | | | | | | | | |
| PS 100A +10V | | 6 | 1x100A | | | | 1x100A | |
| PS 50A + 10V | | 3 | 1x50A | | | | 1x50A | |
| PS 40A +-10A | | 3 | | 3 | 1x40A | | | 1x40A |
| PS 20A +-10V | | 2 | | 2 | 1x20A | | | 1x20A |

### 5.5.-Budget and Price Breakdown

not part of this report

### 5.6.- Anex: Electric Diagrams of the Modules

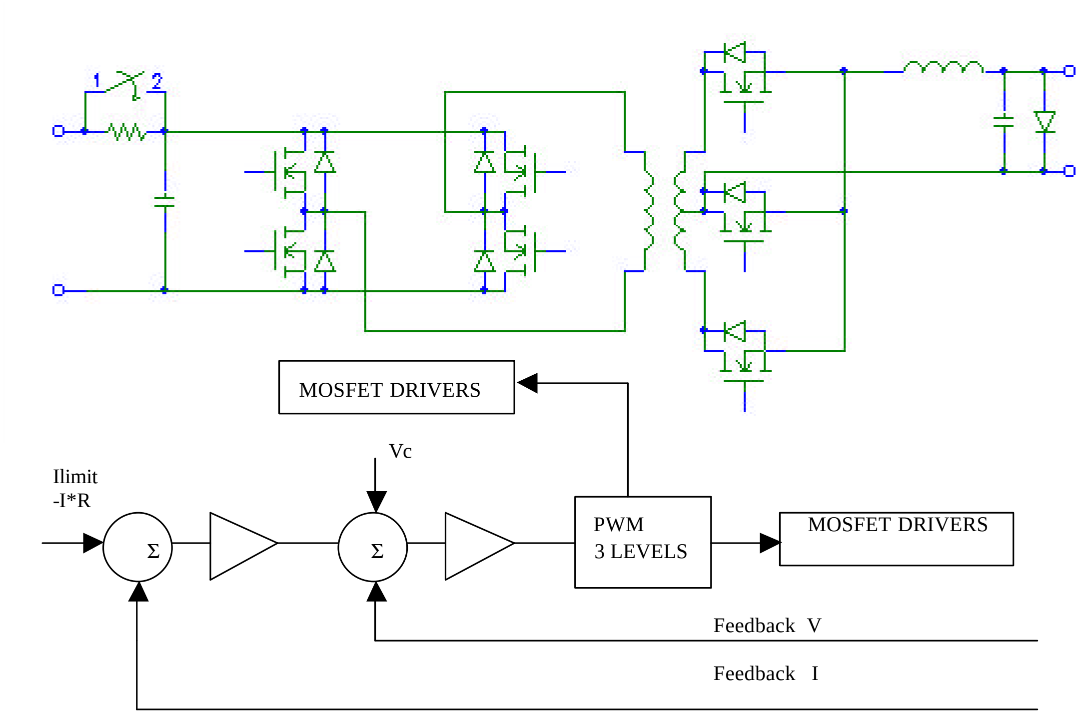


Figure 5.1.- d.c/d.c. Module 25 A ( Input 400 Vdc. Output 0 to +10 V dc)

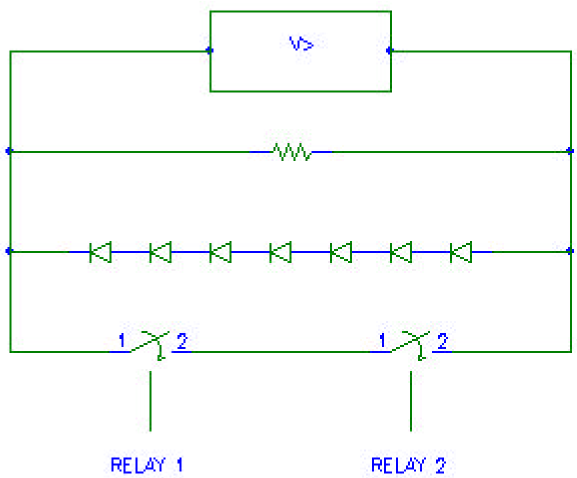


Figure 5.2 Negative Voltage Switch Module (NVS)

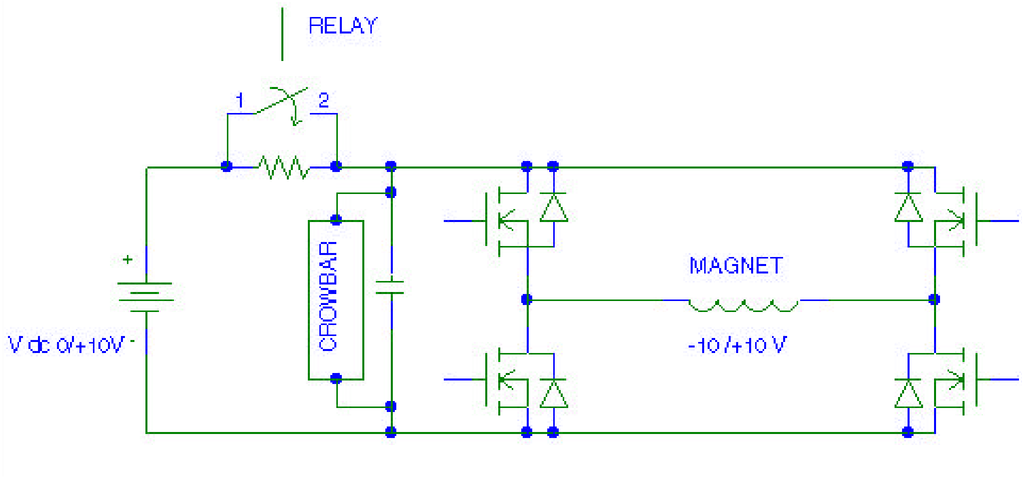


Figure 5.3.- Module d.c./a.c.

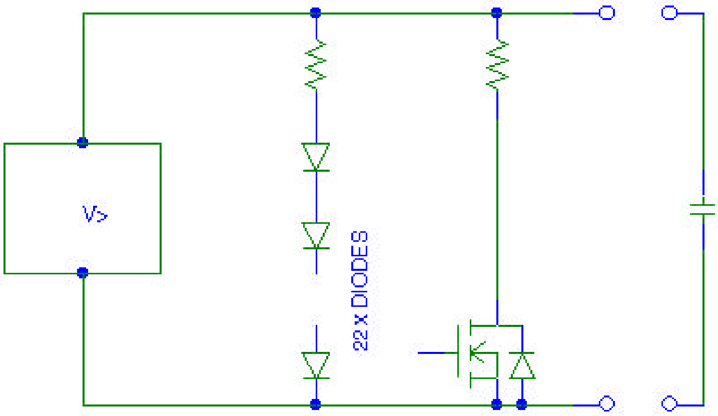


Figure 5.4.- Crowbar

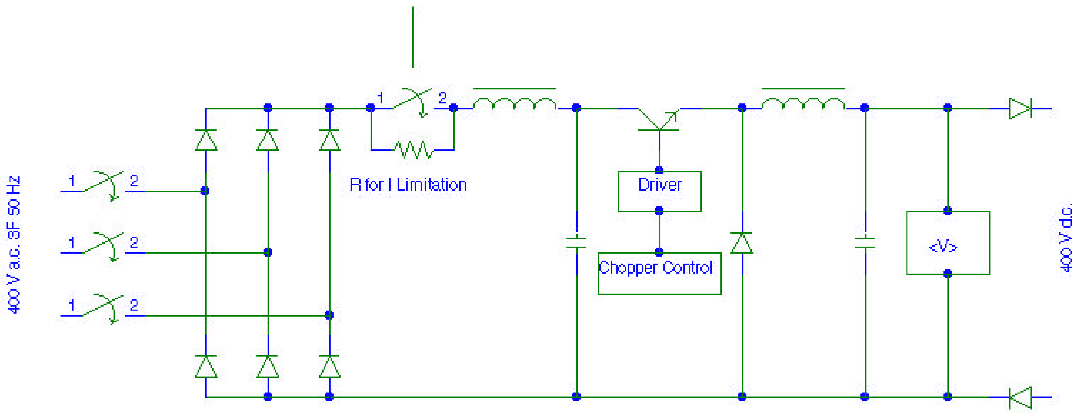


Figure 5.5. Input Module a.c./d.c.

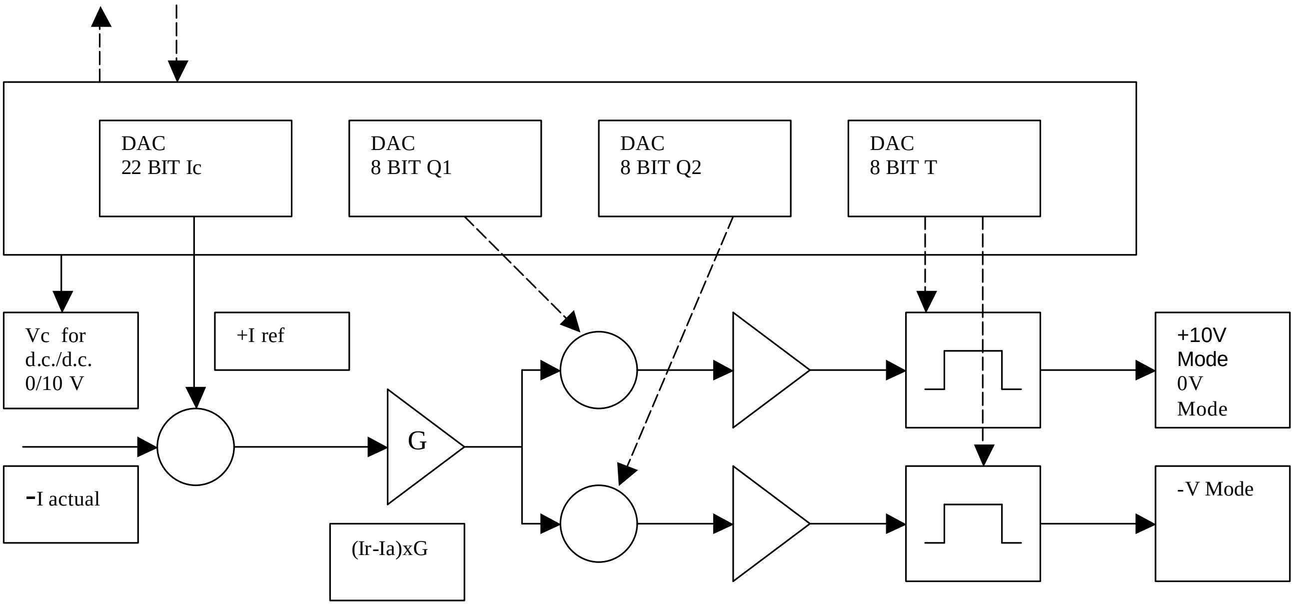


Figure 5.6.- Central Control System

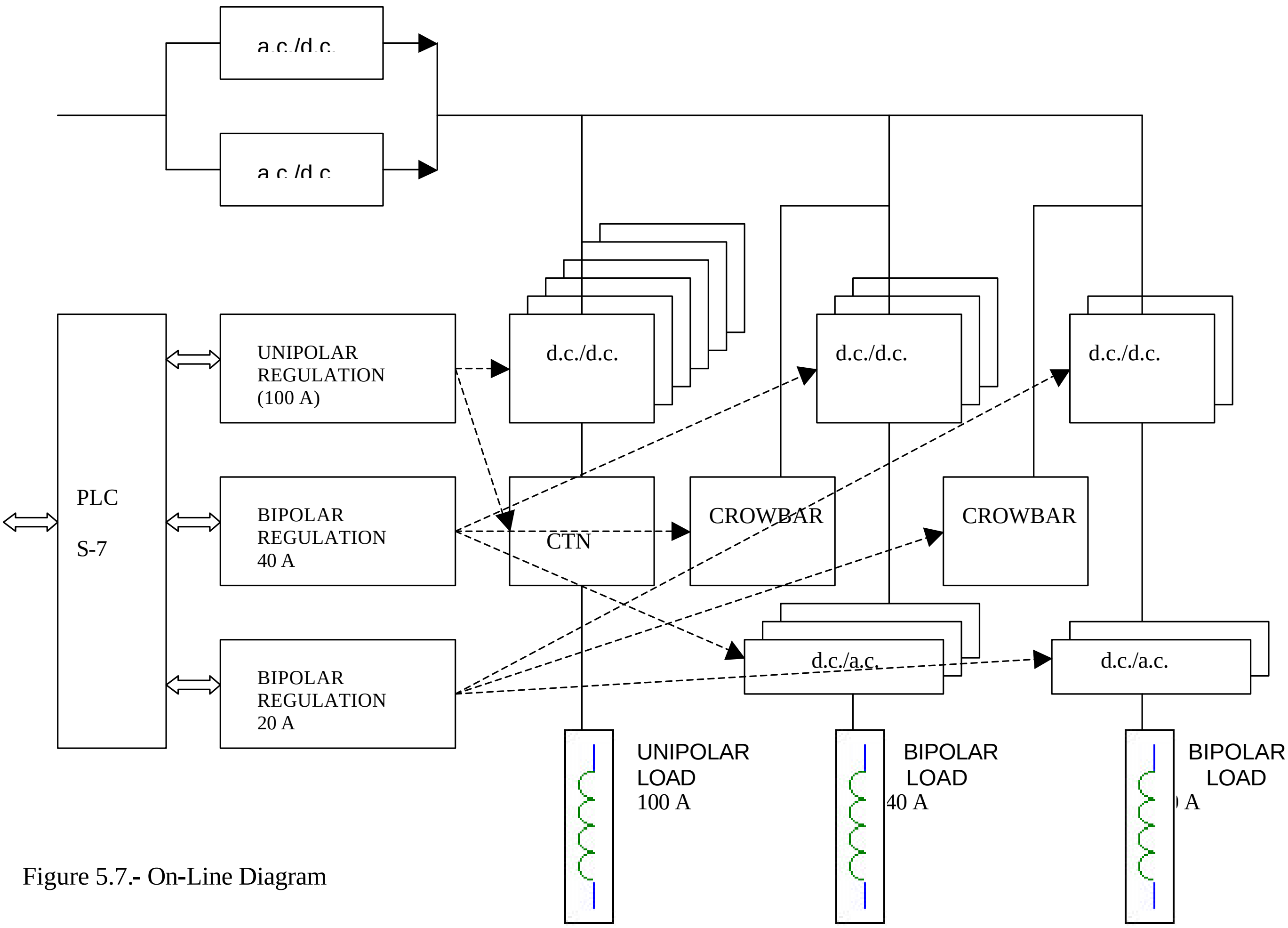


Figure 5.7.- On-Line Diagram