Mitigation of power modulation impact in the MITICA fusion project using supercapacitors: a feasibility study

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Outline

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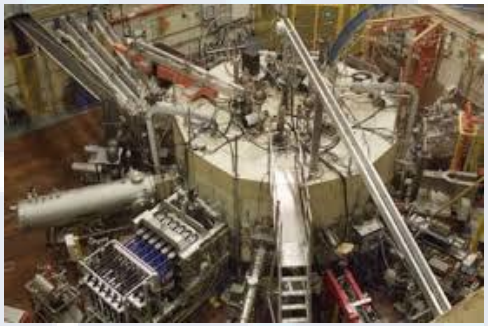
- Introduction on fusion
- MITICA: experiments targets and operating conditions
- Possible methods for the mitigation of power modulation
- Analysis of the supercapacitor solution
- Design of the bank with industrial products
- Issues of the application

Magnetic confinement fusion

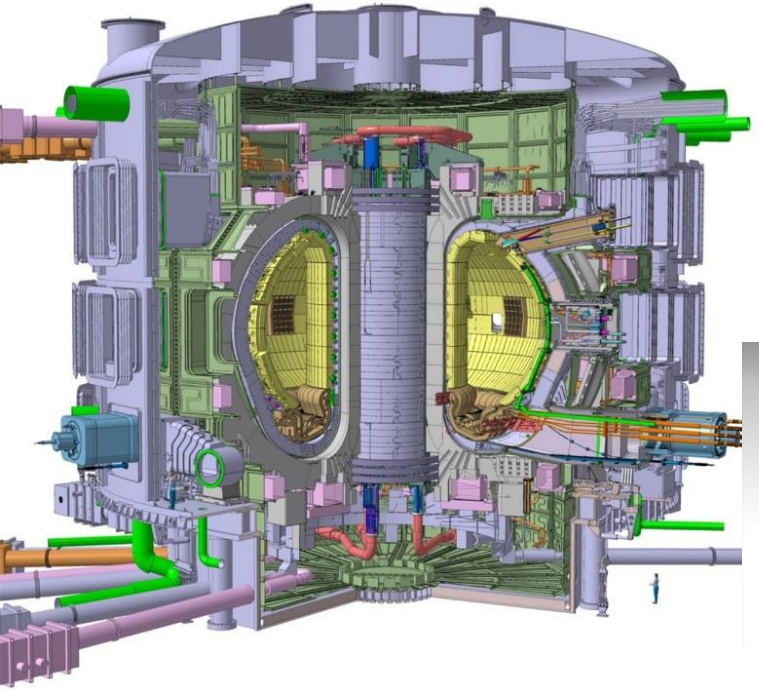
Fusion is currently still in research phase. In the world there are many experimental reactors and research centres, both as national projects and as international cooperations.

Fusion research centres in Italy are in Frascati (ENEA), Padova (consorzio RFX), Milano (IFP) and Napoli (CREATE)

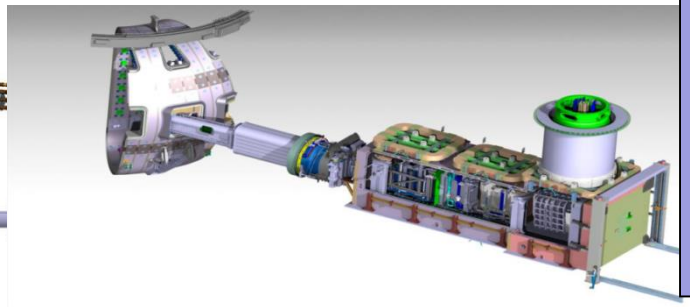


ITER: an international projects is being built in Cadarache (France)
The first fusion experimental reactor producing more energy than that required for the discharge sustainment

ITER NBI systems and MITICA

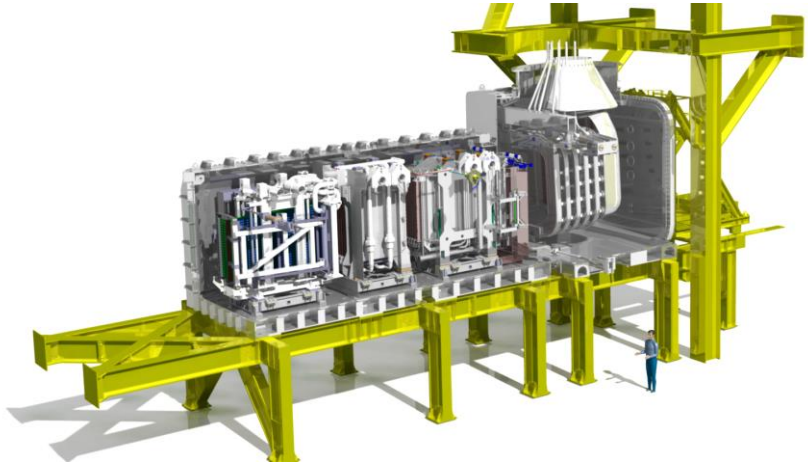


Challenging requirements for power supply systems
Total rating power of the ac/dc converters ~ 2 GVA
Very high power peaks – hundreds of MW
Magnetic energy stored for plasma generation: 640MJ



- 2 NBIs (+1)
- P_{beam} = 16.5 MW
- I = 40 A
- V_{acc} = - 1 MV
- T_{pulse} = 3600 s

MITICA, a full scale prototipe of ITER
Neutral Beam Injector (NBI) to heat the plasma
Under construction in Padova, Consorzio RFX



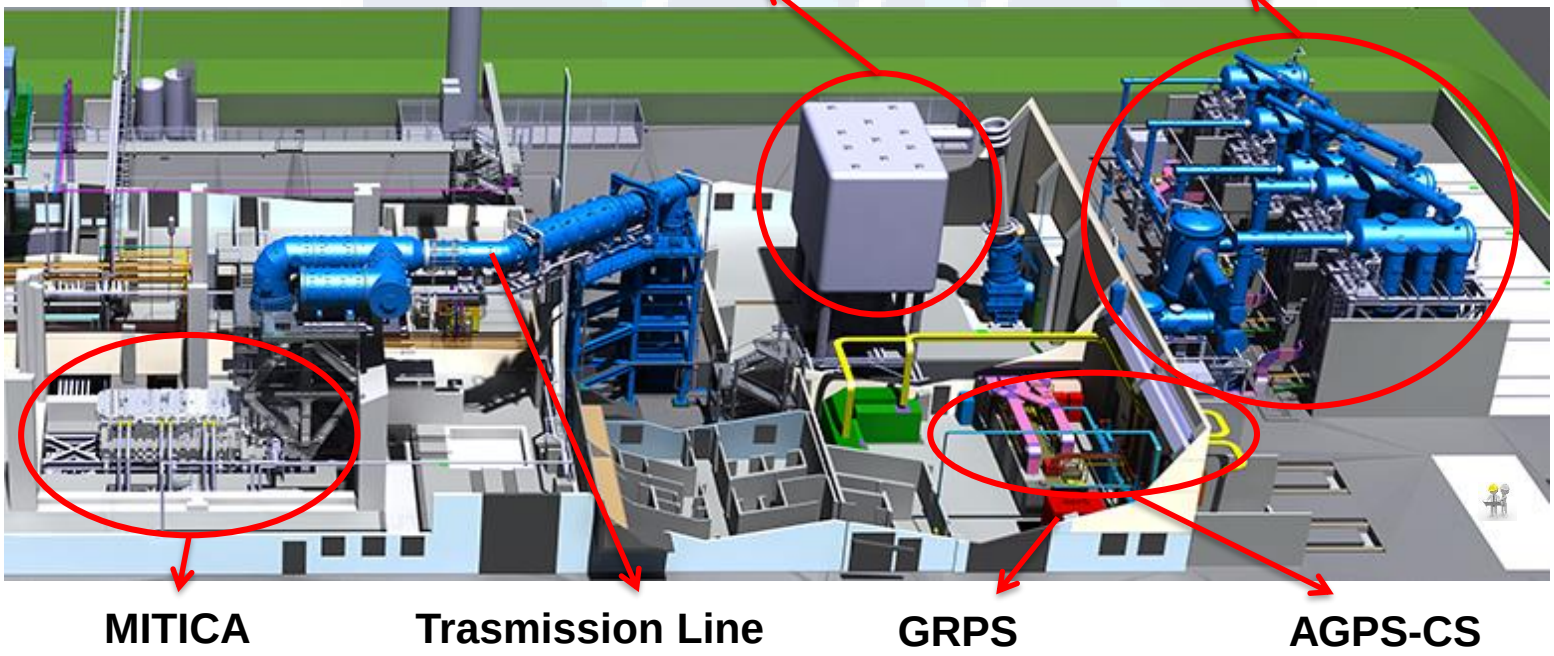
Power supply system of MITICA

MITICA requirements: -60 MW for 1h
-voltages up to -1 MV

→ Very complex system with challenging requirements

The three main power supplies are:

- ISEPS: dedicated to the generation of the negative ions (~ 3.5 MW)
- AGPS: dedicated to the acceleration of the ion beam (~ 55 MW)
- GRPS: supplying load at ground potential (~ 1.5 MW)

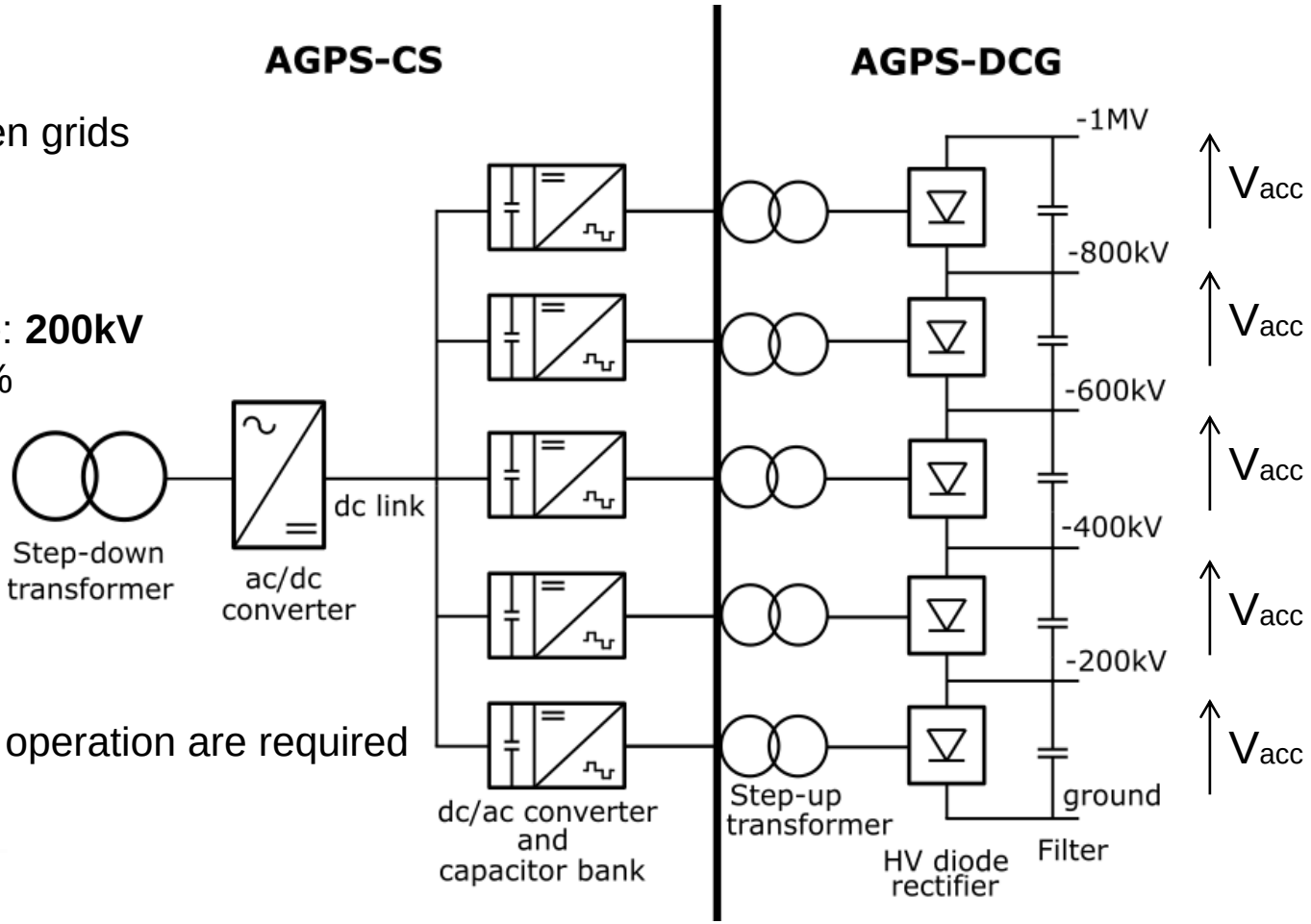


AGPS (Acceleration Grid Power Supply)

Active power absorbed in the operation: **55 MW**
Maximum output dc voltage: **-1MV**
Duty cycle: 1h / 4h
50000 pulses
450000 breakdowns between grids

Main requirements:

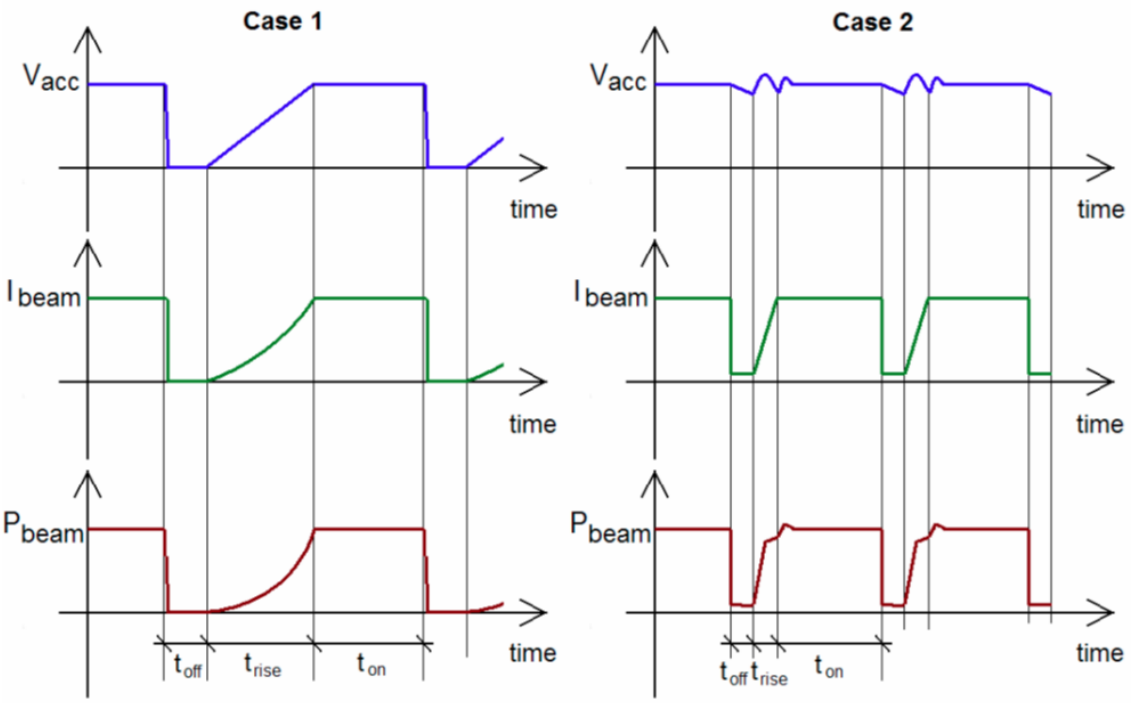
- Output voltage per stage: **200kV**
- Output voltage ripple: 5%
- Ramp-up time: 80ms



Both steady and modulated operation are required

Industrial Supplier: Nidec-ASI S.p.A.

Modulated operation of the AGPS



Case 1: higher energy modulation level

t_{off}= 20 ms
$t_{rise\ max}$ = 80 ms
$t_{on\ min}$= 50 ms

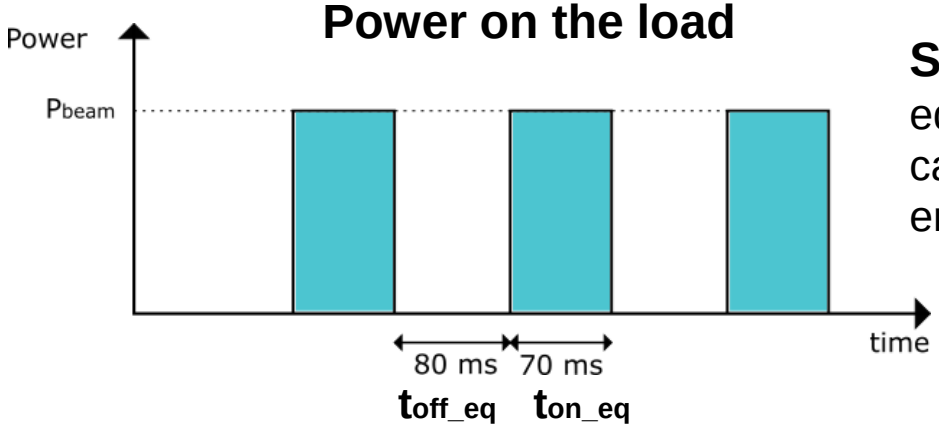
→ Maximum modulation frequency: 7 Hz

Issue: impact on the grid of the power modulation

Mitigation of power modulation impact

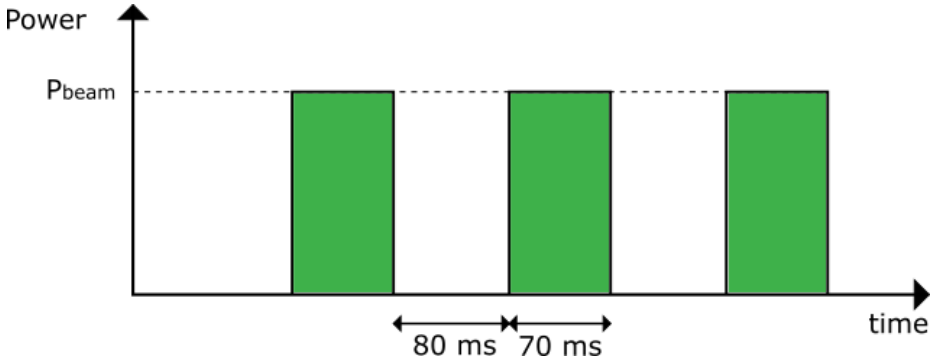
Simplified assumptions for the study

Power on the load

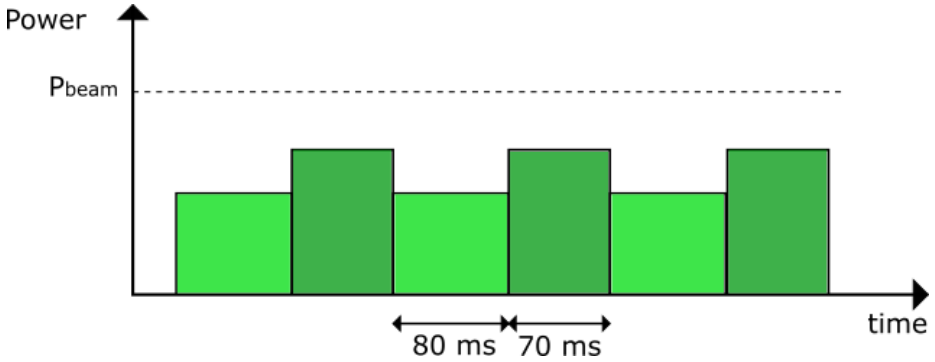


Step-variation
equivalent t_{on} and t_{off} calculated on the basis of the energy absorbed by the load

Power from the grid without energy storage



Power from the grid, with energy storage



Mitigation of power modulation impact

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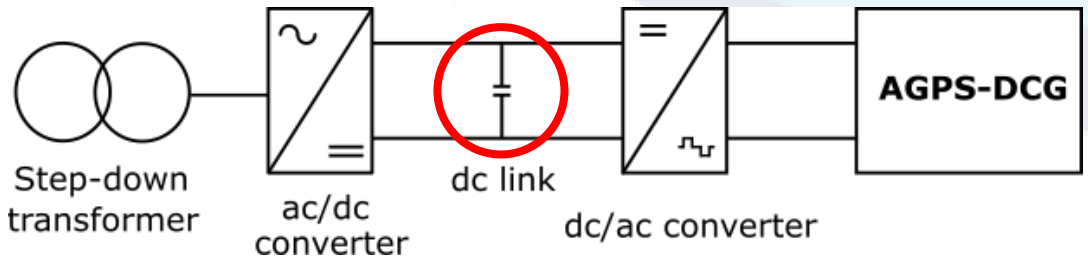
Some solutions have been considered as energy storage systems:

- Battery energy storage ➡ does not allow a proper regulation of the dc link voltage
- Flywheel energy storage ➡ too onerous for this power level
- Magnetic energy storage ➡ possible solution
- Capacitive energy storage ➡ not possible with conventional capacitors (too large volume required)



Using supercapacitors?

Approach explored:
how much to overrate the dc link capacitance to filter the power

Dc link operating condition

The nominal parameters of the dc link are:

- Nominal voltage: **6.5 kV**
- Maximum ripple of dc link voltage: **± 5%**
- Maximum ripple of dc link voltage in transients: ± 10%

Capacitance value of the installed capacitor bank: **39.6mF**
It guarantees the constraints on voltage ripple

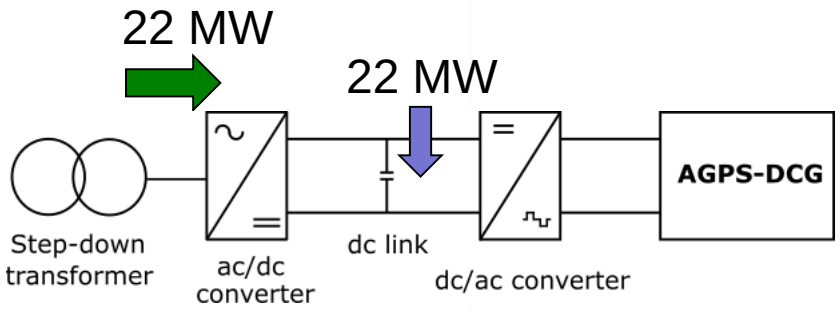
It is a distributed capacitor bank, installed in the inverter cubicles to avoid excessive voltage oscillations on the dc link

The energy stored in the bank during the operation is **840kJ**

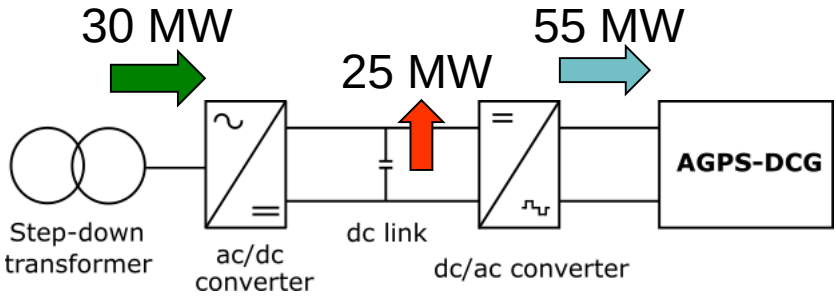
Estimation of the capacitance value

Constraint: requirement on the voltage ripple

No-load period

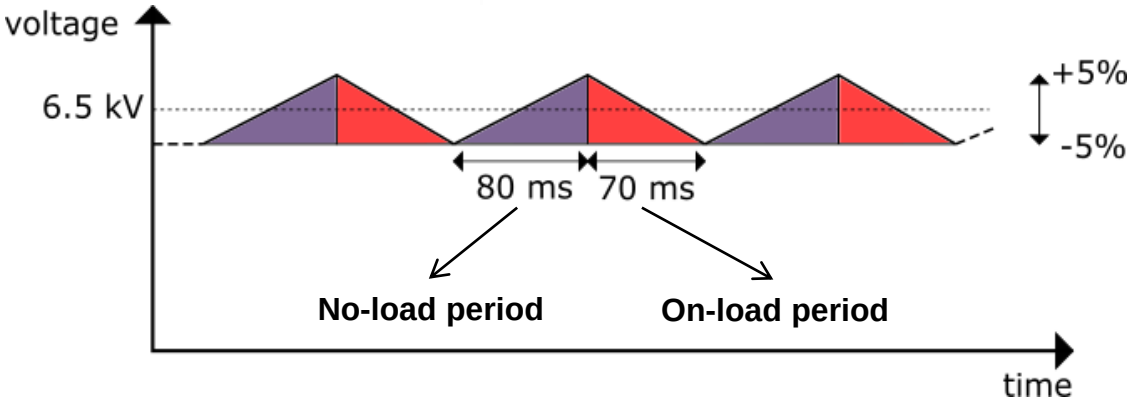


On-load period



The power absorbed from the grid is reduced **from 55 MW to 8 MW**

Dc-link voltage



The minimum capacitance of the bank guaranteeing the requirement on dc link voltage ripple is **0.42 F**

8.8 MJ of stored energy

The dc link design must be changed to a concentrated capacitor bank

Capacitor bank design

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Calculation of the current flowing in the bank, assumptions:
nominal dc link voltage: 6.5 kV
constant current charges-dicharges

	Power on the bank [MW]	Current on the bank [kA]
No-load phase (bank charging)	26.65	3.4
On-load phase (bank discharging)	29.3	3.87

Capacitor bank design, evaluation of:
the number modules in series (dc link voltage: 6.5 kV),
the number of series modules in parallel

Supercapacitor modules considered

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Two supercapacitor modules available on the market have been considered for the analysis, with the following selection criteria:

- High maximum voltage, to reduce the number of modules in series
- High maximum continuous current, to reduce the number of modules in parallel
- Low internal series resistance, to reduce power dissipation

	Skele+on SMOD170V53F	**MAXWELL BMOD0189P051 B2A**
Capacitance	53 F	189 F
Voltage	170 V	51 V
Internal serie resistance (begin of life)	9.4 mΩ	5.6 mΩ
Maximum continuous current (with ΔT= 40°)	566 A	245 A

Characteristic of the bank and power dissipated

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	Skele+on SMOD170V53F	MAXWELL BMOD0189P051 B2A
Number of modules in series	**42**	**140**
Number of parallels	**7**	**16**
Total capacitance of the bank	**8.8 F**	**21.6 F**
Total resistance of 1 serie	44 mΩ	41 mΩ
Charge/discharge current in 1 module	486 / 553 A	213 / 242 A
Power dissipated in a module-charge/discharge	2.22 / 2.87 kW	0.254 / 0.33 kW
Power dissipated in the overall bank-charge	**653 kW**	**569 kW**
Power dissipated in the overall bank-discharge	**844 kW**	**739 kW**
Energy stored in the bank in the operation	**187 MJ**	**456 MJ**

To respect the limit of module continuous current → High capacitance of the bank and energy stored with respect to the need

To reach the specified dc link voltage → High power dissipated due to the high number of modules in serie

Conclusions

The use of supercapacitors as energy storage systems in this application implies the following issues:

- Huge electrostatic energy stored in the system, the bank is extremely oversized with respect to the requirement on energy due to the requirement in power; this is worrying also in case of internal fault in an inverter
- Very high power dissipated in the module due to the high voltage required on the dc link

These issues suggest that the application is unfeasible with the current industrial technologies

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