Power supplies in DTT

ILO Industrial Opportunities Days

Osservatorio Astronomico di Capodimonte, Naples, Italy
7 June 2019

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Power supply System (PSS) = everything electrical in the DTT project

Excluding (partially):

• The standard low voltage distribution inside the buildings
  – Included in the BUI/site procurements

• The Additional Heating (ECRH, ICRH, NBI) PSs
  – I am partially in charge

• PSs for control of ELMs, RWMs
  • Not yet totally defined
Description follows flow of power

- HV line
- PFC and filters
- Electrical distribution
  - SSEN
    - LV in buildings
    - TF coil circuit
      - Transformers, FDUs, busbars
    - Loads
      - Cooling, pumps, ...
    - Auxiliaries
  - PPEN
    - More critical
    - Additional H&CD
    - CS/PF coil circuits
      - Transformers, SNU, busbars
    - Internal coil circuits
HV line (approximate) path

- Roma Est
- Specific substation
- 150-kV 300-MVA line
- ≈15 km
- ENEA Frascati
- DTT
- Terna 400 kV grid
PS layout in ENEA Center

- **Area for new electrical substation (3 transformers 150/20 kV)**
- **MV distribution**
  - Underground cables
- **DTT Hall**
- **Coil PS Area (19 Ps)**
- **150-kV line** (from TERNA)
- **Old substation**
- **New substation**
- **North Load Center**
- **South Load Center**
- **PS Load Center**
- **cos\(\phi\) correction, harmonics and flicker filters**
- **DC busbars**
Single Line Diagram

SSEN

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Options for power factor correction (+harmonics, flicker...)

1. STATCOM (SVC)
2. Rotating synchronous compensator (condenser)
Summary of the 19 coil PSs

Operation: $\approx 100$ s  
Period: every 3600 s

Superconducting coils:  
• 12 CS/PF

Copper coils:  
• 2 VS (equatorial)  
• 4 IV (under divertor)  
• ELM, RWM

Continuative (days):  
• 1 TF
TFC PS: 45 kA, 100 V

Step-down transformer(s)

MV 20 kV

Base PS

Crow-bar (unidirectional)

Slow: charge in minutes, flat-top for days

Superconductors

6 coils

FDU

Pyrobreaker

6 coils

Critical: each > 6 kV
Summary of the 19 coil PSs

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Max I, V ratings (old DN, SF)

SF had a lot of power in the middle of the scenario
Breakdown with dynamic compensation

[Bar chart showing maximum PS voltage for different categories across various labels (CS3U, CS2U, CS1U, CS1L, CS2L, CS3L, PF1, PF2, PF3, PF4, PF5, PF6).

Line graph showing voltage (V) as a function of time (t) in seconds (s), with different lines representing different categories and values ranging from -4000 to 0.]

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Functional scheme of a SNU (with external FDU)

From Base PS

IGCT

\[ \text{2x12} \]

Pyrobreaker (back-up protection)

To CS/PF coils

100 mΩ

R

100 mΩ

100 mΩ

100 mΩ

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Official scenario for Terna

DTT with $\cos \phi = 0.9$ or AFE

H&CD

DTT with energy conservation

CS & PF

SSEN

DTT thyristors without correction

Apparent power (MVA)

Time(s)

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6 CS + 6 PF PS topology

Basic principles:
- Low impact on the external grid
- Low power input: 20 kV, <100 kW (energy recovery)
- Dynamic compensation during breakdown
- Modularity
Working prototype

SCPS: 2 kA, 10 s

Dimensions: 120 x 60 x 190 cm = 1.4 m³

Wheels to move it!

Connections: just the plug and the load

Previous system: 2 kA, 1 s

20 kV / 324 V transformer
195 x 110 x 226 cm

AC/DC converter
176 x 75 x 270 cm

20 kV line

324 V line

20 kV circuit breakers + safety switches (also for another converter)
60 x 150 x 220 cm

Total dimensions: > 10 m³ (> 7 times)
+ dedicated 20-kV line
and 324-V line

Fixed installation
with many connections
Rough estimation of possible final configuration

- Total Energy Storage for 12 PSs: 600 MW, 3600 MJ, 960 kWh
- Moreover, ENEA has SMESs and flywheels
- Comparison:
  - Korea: 25 MW supercap in several facilities
  - Endesa STORE, Canary Islands, Spain supercap: 4 MW, 20 MJ
  - Terna, Sicilia + Sardegna supercap: 1+1 MW, 1+1 MJ
  - Terna has some battery systems in order of 10 MW
  - DTT could be an “electrostatic lake” (Italy has 4 hydro-storage lakes at 1 GW)

If you like to know more: [www.supercap.org](http://www.supercap.org)
## Main characteristics of the base PSs

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>CS/PF PSs</th>
<th>VS coil PSs</th>
<th>IV coil PSs</th>
<th>ELM/RWM PSs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Position</strong></td>
<td>Ex-vessel</td>
<td>In-vessel equatorial</td>
<td>Around divertor</td>
<td>Non-axisymmetric</td>
</tr>
<tr>
<td><strong>Load coil material</strong></td>
<td>Superconducting</td>
<td>Copper</td>
<td>Copper</td>
<td>Copper</td>
</tr>
<tr>
<td><strong>Number of PSs</strong></td>
<td>12</td>
<td>2</td>
<td>4</td>
<td>To be defined</td>
</tr>
<tr>
<td><strong>Number of quadrants</strong></td>
<td>4</td>
<td>4</td>
<td>4 (2 possible)</td>
<td>4</td>
</tr>
<tr>
<td><strong>Duty cycle and typical scenarios</strong></td>
<td>&lt;200s/3600s</td>
<td>100s/3600s</td>
<td>Flat-top ≤40 s</td>
<td>100s/3600s</td>
</tr>
<tr>
<td><strong>Ramps</strong></td>
<td>Up 60 s, down 30 s</td>
<td>None</td>
<td>To be defined</td>
<td>None</td>
</tr>
<tr>
<td><strong>Number of converter transformers</strong></td>
<td>1 (also for more coils)</td>
<td>1</td>
<td>2</td>
<td>To be defined</td>
</tr>
<tr>
<td><strong>Adopted topology</strong></td>
<td>DC link storage H-bridge</td>
<td>DC link storage H-bridge</td>
<td>Thyristor bridge</td>
<td>DC link Same input power</td>
</tr>
<tr>
<td><strong>Semiconductor technology</strong></td>
<td>IGBT (IGCT)</td>
<td>IGBT</td>
<td>Thyristor</td>
<td>Silicon carbide</td>
</tr>
<tr>
<td><strong>Energy stored in DC link per PS</strong></td>
<td>&gt;300 MJ</td>
<td>&gt;100 MJ</td>
<td>None</td>
<td>To be defined</td>
</tr>
<tr>
<td><strong>Charger</strong></td>
<td>Diode or AFE</td>
<td>Diode or AFE</td>
<td>None</td>
<td>Diode/thyristor</td>
</tr>
<tr>
<td><strong>Input power</strong></td>
<td>&lt;50 kW</td>
<td>&lt;100 kW</td>
<td>&gt;1 MW</td>
<td>&lt;1 MW</td>
</tr>
<tr>
<td><strong>Number of basic units</strong></td>
<td>12</td>
<td>10</td>
<td>5</td>
<td>To be defined</td>
</tr>
<tr>
<td><strong>Current</strong></td>
<td>±30 kA</td>
<td>±25 kA</td>
<td>±25 kA</td>
<td>To be defined</td>
</tr>
<tr>
<td><strong>No-load DC voltage</strong></td>
<td>1000 V</td>
<td>200 V</td>
<td>200 V</td>
<td>To be defined</td>
</tr>
<tr>
<td><strong>Worst-case DC voltage</strong></td>
<td>600 V</td>
<td>200 V</td>
<td>200 V</td>
<td>To be defined</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Fast</td>
<td>Fast modulation</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td><strong>Controlled quantity</strong></td>
<td>Current or voltage</td>
<td>Current or voltage</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td><strong>Supporting SNU</strong></td>
<td>Static</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>Cooling</strong></td>
<td>Raw water</td>
<td>Raw water</td>
<td>Demi water</td>
<td>Air</td>
</tr>
</tbody>
</table>
Each PS has a dedicated area 13x13 m. In each area 3-4 standard (40 feet) containers.
DC busbars and tunnels

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**DTT Hall**

- **Road**
- **Cover, if necessary**
  - **Container**
  - **Area 13x13 m**
  - **40 feet containers**

<table>
<thead>
<tr>
<th>Corridor Type</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tipo 1</td>
<td>3x3m</td>
</tr>
<tr>
<td>Tipo 2</td>
<td>1.5x3m</td>
</tr>
<tr>
<td>Tipo 3</td>
<td>2x1m</td>
</tr>
</tbody>
</table>

- **>3 km aluminum (or copper) bars**
- **Critical: TF 45 kA**
- **Proposal: HTS**
Assumed scenario and performances for additional heating

Poor knowledge of AH scenarios (and real efficiency), including fast variations

<table>
<thead>
<tr>
<th>H&amp;CD system</th>
<th>Initial mix</th>
<th>Maximum expected upgrade</th>
<th>Wall-plug efficiency $\eta$</th>
<th>Power factor $\cos \phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECRH</td>
<td>15 MW</td>
<td>30 MW</td>
<td>35-40%</td>
<td>0.9</td>
</tr>
<tr>
<td>ICRH</td>
<td>3 MW</td>
<td>9 MW</td>
<td>40%</td>
<td>0.9</td>
</tr>
<tr>
<td>N-NBI</td>
<td>7.5 MW</td>
<td>15 MW</td>
<td>40-45%</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Typical DTT scenario (and official scenario for Terna)
# Summary of PSS Calls for Tenders

<table>
<thead>
<tr>
<th>1</th>
<th>High-voltage line</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Electrical substation</td>
</tr>
<tr>
<td>3</td>
<td>Power factor correction and filters</td>
</tr>
<tr>
<td>4</td>
<td>Electrical distribution (SSEN &amp; PPEN)</td>
</tr>
<tr>
<td>5</td>
<td>Toroidal Field Coil PS</td>
</tr>
<tr>
<td>6</td>
<td>Toroidal Field Coil fast discharge units</td>
</tr>
<tr>
<td>7</td>
<td>CS/PF PSs and SNU (some BPSs)</td>
</tr>
<tr>
<td>8</td>
<td>Internal Coil PSs</td>
</tr>
<tr>
<td>9</td>
<td>DC busbars (CS, PF, TF, IC)</td>
</tr>
<tr>
<td>10</td>
<td>Others (dummy loads, auxiliary, transducers, …)</td>
</tr>
</tbody>
</table>

**Color code:**
- **Preliminary analysis**
- **Prepare and launch the Call for Tender**
- **Call for Tender**
- **Design**
- **Manufacturing and factory tests**
- **Installation (and procedures for the HV line)**
- **Test**
- **Commissioning**

Remember, not including:
- H&CD PSs
- ELM, RWM PSs
- LV in buildings
Short-term planning: test facility for PF, CS, TF coils

- CS and PF PSs are very different from TF PS
- Different PSs also in test facility
- Both ready by 2021 (2022)
- Proposal
  1. A 40” container for PF6 and CS0, including SNU but with shorter scenario (less energy)
  2. A 40” container for 18 TF coils, including FDU but with reduced resistance for same $\tau = 5\ s$
Thank you for your attention

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