Power Supply and Energy Extraction System for the PANDA Solenoid Magnet

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- Introduction
- Powering Circuit
- Cabling, racks position
- Calculations
- Power Supply, parameters, drawings
- Energy Extraction System, parameters, drawings
- Dump resistor, drawings
- Control Electronics
- Status
Requirements for the Power Supply and Energy Extraction System:

- Current in a circuit 5100 A;
- The amount of the stored energy to be extracted is 22MJ. Stored energy should be extracted to the external dump resistor with the value of 0.1 Ohm. The active elements of the dump resistor should not be hotter than 100°C;
- Middle point should be introduced and grounded in order to minimize the voltage between the coil and ground.
- Dump resistor should have as minimal as possible stray inductance and must be installed in parallel with the extraction switch;
- The opening time of the energy extraction switch is not specified;
Cabling diagram

- Dump Resistor 0,1 Ohm
- Energy extraction switch
- Power Supply 5100 A
- Magnet

Connections:
- EES, out to EES, in
- PS, - to PS, +
- flag - to flag +
- Mag - to Mag +
Cabling diagram

Dump Resistor
0,1 Ohm

Energy extraction switch

Power Supply
5100 A

EES, out
EES, in
PS, -
PS, +
flag -
flag +
3ph, 400V, 50Hz
8 cables per pole
false floor
water
Mag +
Mag -
Racks position
### Calculations

#### Mass of the stainless steel of the Dump Resistor

<table>
<thead>
<tr>
<th>Room temperature, °C</th>
<th>dT, K</th>
<th>Cv, J/kg*K</th>
<th>W, MJ</th>
<th>T, °C</th>
<th>m, kg</th>
<th>Number of racks</th>
<th>L, Hn</th>
<th>I, A</th>
<th>Stored Energy, MJ</th>
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<tbody>
<tr>
<td>25</td>
<td>60</td>
<td>500</td>
<td>22</td>
<td>85</td>
<td>733</td>
<td>2</td>
<td>1,69</td>
<td>5100</td>
<td>22</td>
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<td>25</td>
<td>80</td>
<td>500</td>
<td>22</td>
<td>105</td>
<td>550</td>
<td>2</td>
<td>1</td>
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<td>25</td>
<td>100</td>
<td>500</td>
<td>22</td>
<td>125</td>
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<td>13</td>
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<td>500</td>
<td>13</td>
<td>105</td>
<td>325</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>100</td>
<td>500</td>
<td>13</td>
<td>125</td>
<td>260</td>
<td>1</td>
<td>1</td>
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<td></td>
</tr>
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</table>

#### Cables resistance and voltage drop

<table>
<thead>
<tr>
<th>ρ, Ohm * m²/m²</th>
<th>crosssection, mm²</th>
<th>Cable length, meters</th>
<th>R, mOhm</th>
<th>delta U, V</th>
<th>P, W</th>
<th>Current density, A/mm²</th>
<th>Cooling type</th>
<th>Cables, total weight, kg*</th>
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<tbody>
<tr>
<td>0,018</td>
<td>3000</td>
<td>20</td>
<td>0,120</td>
<td>0,612</td>
<td>3121,2</td>
<td>1,7</td>
<td>air</td>
<td>536</td>
</tr>
<tr>
<td>0,018</td>
<td>3200</td>
<td>20</td>
<td>0,113</td>
<td>0,574</td>
<td>2926,1</td>
<td>1,59</td>
<td>air</td>
<td>572</td>
</tr>
<tr>
<td>0,018</td>
<td>1000</td>
<td>20</td>
<td>0,360</td>
<td>1,836</td>
<td>9363,6</td>
<td>5,10</td>
<td>water</td>
<td>179</td>
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</table>

<table>
<thead>
<tr>
<th>Current, A</th>
<th>kg/m³</th>
<th>5100</th>
<th>8930</th>
</tr>
</thead>
</table>

* without isolation
General design of four paralleled current sources controlled by ACU

ACU

Multifunction module

I/F

DCL

USI

ADC

DCCT

CS – local current feedback current sensor
DCCT – digital control loop current sensor
ACU – Adaptive Control Unit
DCL – Digital Control Loop
CIBm – Control & Interface Board (master)
CIBs – Control & Interface Board (slave)
GSP15kW  Front Panel Description

1. Input Power ON/OFF Switch
2. Air Intake allows zero stacking for maximum system flexibility and power density.
3. Reliable Detent Encoders for settings and Menu navigation.
4. High Contrast/Brightness display with wide viewing angle, 16 segment LCD
5. Function/Status LEDs: Active modes and function indicators
6. Pushbuttons allow flexible user configuration
Power Supply (Current Source – TDK-Lambda Genesys+, 10V, 1500A)

GSP15kW Rear Panel Description

1. Isolated Analog Programming, Monitoring and other control connector (DB26 Female)
2. USB Interface connector (Type B).
3. RS-232/RS-485 IN/OUT Remote Digital Interface (RJ-45 type) for Multi-Drop connection
4. LAN (LX1 1.5) Interface connector (RJ-45 type with LAN status indicators).
5. Auto paralleling Bus connectors (mini I/O type) for connecting Master unit-to-Slave and slave unit-to-slave unit.
6. Remote/Local Output Voltage Sense Connections (spring cage).
7. Output Connections: Rugged busbars for models up to and including 100V Output;
   Plug connector: PHOENIX CONTACT DFK-IPC 16/4-STF-10.16 for models with Outputs >100V (shown).
8. Input: 208VAC, 400VAC & 480VAC Three Phase, 50/60 Hz.
   AC Input Plug Connector: PHOENIX CONTACT DFK-PC 16/4-ST-10.16 with strain relief.
9. Optional Interface Position for IEEE 488.2 SCPI or AnyBus Interface.
10. Exhaust air assures reliable operation when zero stacked.
11. Functional Ground connection (M4x8mm stud).
Power Supply (Current Source – TDK Lambda Genesys+, 10V, 1500A)

Main parameters of the TDK-Lambda Genesys+ 10V, 1500A power supply:

- Nominal output power 15kWt;
- Nominal output current 1500A;
- Nominal output voltage 10V;
- Load regulation in current mode - < 0.08% from nominal;
- Output ripples in voltage:
  - 5Hz-1MHz - < 8mV rms,
  - 20MHz – < 75mV p-p;
- Control Interface – RS232/485, USB, LAN
- Form factor Euro Rack 19”, 3U
- External conditions – room temperature 10 – 350°C;
- Input power line – 3 phases 400V with neutral.
- Cooling – forced air,
- Sizes (WxHxD), mm, 423 x 132,5 x 640, weight 23.5kg.
- Analog values:
  - Output_Current
  - Output_Voltage
- Interlocks and Statuses:
  - PS OK;
  - CV/CC signal;
  - LOCAL/REMOTE Analog control;
  - LOCAL/REMOTE Analog signal;
  - ENABLE/DISABLE Signal;
  - INTERLOCK (ILC) control;
  - Programmed signals;
  - TRIGGER IN / TRIGGER OUT signals;
**Power Supply 5100A, parameters**

- Nominal output power 51kWt;
- Nominal output current 5100A;
- Nominal output voltage 10V;
- 8 hours run Stability - < 0.01% from nominal;
- Output ripples in voltage:
  - 5Hz-1MHz - < 8mV rms,
  - 20MHz – < 75mV p-p;
- Control Interface – USI
- Form factor Euro Rack 42” height
- External conditions – room temperature 10–35°C;
- Input power line – 3 phases 400V with neutral.
- Cooling – distilled water not warmer than 30°C, for the diodes
- Nominal input pressure 13 bars,
- Water consumption 2 liters/min,
- Water gradient with the maximal power < 10°C
- Sizes 2000mm x 800mm x 800m, weight 300kg.
Power Supply 5100A, parameters

- Analog values:
  - Output_Current
  - Output_Voltage
  - Ireg_Error

- Interlocks and Statuses:
  - Overcurrent (I > “Imax”);
  - Overpower (Pload > “Pmax”);
  - Phase distortion for more than 20% ;
  - Over temperature of the power part;
  - Earth fault
  - Fast_Power_Abort
  - Emergency_stop
  - Doors_open
  - WaterFlow
  - Circuit_Breaker_On
  - Contactor_On
  - Current Sharing
  - EES_Closed
  - PS_Ready
Power Supply 5100A, drawings

- Contactor, terminals
- 5100 A busbars
- GSP
- diodes
- ACU
- vent
dcct
eibm
- GSP
- flexibles
- EMC filter
- 1500 V copper (cap) 400V 50Hz
AC input power distribution diagram

Common: Siemens SRT105/64B34
EMC filter: Schaffner FN 2270
Circuit breaker: Siemens SFT804
Terminal: Wieland-Werke WDU 5SN and WDU 2SN
**Power Supply 5100A, drawings**

- **EMC Filter Schaffner FN3270, 150A**
- **Contactor Siemens 3RT, 150A**
- **Circuit Breaker Siemens 5SY6306, 150A**
- **Terminals Weidmuller WDU 50N, 150A**
Powering circuit

PS, 5100 A

EES switch

Snubber

R_dump, 0,1

PS, 5100 A

Magnet

0,69

0,31

0,69

Magnet

DCCT

EES switch

Snubber

R_dump, 0,1
Energy Extraction System

Energy Extraction System, general layout
**Energy Extraction System**

**Electromechanical Breaker and help of snubber against the arc - example**

Voltage over the contacts while opening the circuit with $C_{snab} = 0$

Voltage over the contacts while opening the circuit with $C_{snab} = 0.8 \text{ mF}$
Energy Extraction System, parameters

<table>
<thead>
<tr>
<th>№</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Nominal current</td>
<td>5100</td>
<td>A</td>
</tr>
<tr>
<td>2.</td>
<td>Maximal current</td>
<td>5400</td>
<td>A</td>
</tr>
<tr>
<td>3.</td>
<td>Maximal extracted energy</td>
<td>22</td>
<td>MJ</td>
</tr>
<tr>
<td>4.</td>
<td>Current polarity</td>
<td>Any</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Inductance in a circuit</td>
<td>1,69</td>
<td>Hn</td>
</tr>
<tr>
<td>6.</td>
<td>Dump resistor value</td>
<td>0,1 ± 5%</td>
<td>Ohm</td>
</tr>
<tr>
<td>7.</td>
<td>Maximal overtemperature of the Dump Resistor</td>
<td>60</td>
<td>K</td>
</tr>
<tr>
<td>8.</td>
<td>Time constant for the energy extraction</td>
<td>16,9</td>
<td>s</td>
</tr>
</tbody>
</table>

Electromechanical Breaker as a main protection element (Switch)
Energy Extraction System, drawings

VA55-43

R_equalizing

Snubber

flexibles

DCCT

(to copper flag)
Energy Extraction System, drawings

Insulation
Standard insulation material is a PVC-tube. Other materials like silicone, glass-fibre- or shrinking tubes etc. on request. Please notice our design with a special heat resistance fire protection hose on page 36 of this catalogue.

Special designs
In special design we deliver also connectors made out of tinned wires or with coated contact areas (tin-, nickel-, silver- or gold plated) or in coordination with your application according to your drawings, samples or wishes.

<table>
<thead>
<tr>
<th>Part-No.</th>
<th>cross-section</th>
<th>technical data</th>
</tr>
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<tbody>
<tr>
<td>uncoated</td>
<td>PVC-insulated</td>
<td>dimensions mm</td>
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<td>15376</td>
<td>15446</td>
<td>A  B  C  D  E  F  G  H</td>
</tr>
<tr>
<td>15379</td>
<td>15449</td>
<td>70  300 A  30  15  7  7,5  15  8,5</td>
</tr>
<tr>
<td>15380</td>
<td>15450</td>
<td>95  360 A  40  20  9  10  20  9,2</td>
</tr>
<tr>
<td>15381</td>
<td>15451</td>
<td>120 420 A  40  20  9  10  20  10,0</td>
</tr>
<tr>
<td>15382</td>
<td>15452</td>
<td>150 480 A  50  25  11  12,5  25  11,5</td>
</tr>
<tr>
<td>15383</td>
<td>15453</td>
<td>185 570 A  50  25  11  12,5  25  13,5</td>
</tr>
<tr>
<td>15384</td>
<td>15454</td>
<td>240 670 A  60  32  11  16  32  12,8</td>
</tr>
<tr>
<td>15385</td>
<td>15455</td>
<td>300 760 A  80  40  14  20  40  13,3</td>
</tr>
<tr>
<td>15386</td>
<td>15456</td>
<td>400 850 A  80  40  14  20  40  15,5</td>
</tr>
<tr>
<td>15387</td>
<td>15457</td>
<td>500 1100 A  80  40  14  20  40  23,5</td>
</tr>
<tr>
<td>15388</td>
<td>15458</td>
<td>600 1250 A  80  55  14  20  40  18,8</td>
</tr>
<tr>
<td>15389</td>
<td>15459</td>
<td>700 1375 A  80  55  14  20  40  20,2</td>
</tr>
<tr>
<td>15390</td>
<td>15460</td>
<td>750 1450 A  80  55  14  20  40  21,8</td>
</tr>
<tr>
<td>15391</td>
<td>15461</td>
<td>850 1550 A  80  55  14  20  40  22,3</td>
</tr>
<tr>
<td>15392</td>
<td>15462</td>
<td>1000 1800 A  80  55  14  20  40  20,0</td>
</tr>
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<td>15393</td>
<td>15463</td>
<td>70  300 A  15  15  7  8,5</td>
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<td>95  360 A  20  20  9  10  8,5</td>
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<tr>
<td>15396</td>
<td>15466</td>
<td>150 480 A  25  25  11  12,5  11,5</td>
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<td>185 570 A  25  25  11  12,5  13,5</td>
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<td>15399</td>
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<td>15402</td>
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<td>600 1250 A  40  55  14  20  18,6</td>
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<td>700 1375 A  40  55  14  20  20,2</td>
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<td>15404</td>
<td>15474</td>
<td>750 1450 A  40  55  14  20  21,8</td>
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</tr>
<tr>
<td>15406</td>
<td>15476</td>
<td>1000 1800 A  40  55  14  20  20,0</td>
</tr>
</tbody>
</table>

Remark:
All information about current-load are approximate values for single laying of air cooled cables and ambient temperature +35°C and a conductor temperature of circa +70°C. The temperature of the conductor is in dependent on the installation, the application, the cooling, the ambient temperature etc. so that if necessary reducing factors are to be considered. The reducing factor for an insulated design depending on the application is between 15-20%.
Energy Extraction System, drawings
Energy Extraction System, drawings

- DCCT
- Fixation for DCCT
- Central busbar for DCCT

flexibles
Energy Extraction System, schematics

Wiring diagram for EES
Energy Extraction System, schematics

Breaker Board

Diagram of the Breaker Board with various components and connections.

Title: Breaker Board

Sheet: 1 of 1

File: D:\Freshman_3ES_Breaker_Board.Sch.pdf
Energy Extraction System, schematics

Measurement Board
Dump Resistor, drawings

One section out of six, assembled

Welding

Two bifilar layers of 1.5mm stainless steel with G10 between

1.5±0.5
Dump Resistor, drawings
Frame to support the sections
Dump Resistor, drawings

G10 supports for the sections
Dump Resistor, drawings

Two sections, top view

Vertical natural cooling
The main objective is to provide the interface between GSI and BINP control electronics based on GSI standard conception. To achieve it is used GSI standard control module, Adaptive control unit (ACU) and Interface control modules (ICM). ACU module is used as a bridge between GSI high-level control system and devices developed by BINP such as power supply and energy extraction. Communication is provided by GSI Universal serial interface (USI).

The general control conception for CBM magnet’s power supply and energy extraction system
Power Supply based on the commercial PS type of Genesys Plus (GSP) and has its own local current feedback; the global current feedback is looped with the external DCCT and controlled by ACU module. ACU module calculates current error according to DCCT value and transmits it to CIBm module by USI interface. CIBm module forms analog control value to GSP. CIBm also collects data, interlocks and statuses from GSP by digital interface.
**Control and Interface Board master**

Control and Interface Board master (CIBm) 1U module carries out interconnection between ACU and GSP module. Interconnection is provided mainly by USI interface. CIBm module measures water flow in cooling circuits of the diodes, controls AC mains contactor and reads its status. Emergency stop interlock (placed on the front panel of CIBm module) and doors interlock are also processed by CIBm.

In addition, CIBm module collects abort signals from independent parts of controlling GSI Machine protection system (MPS), Quench detection system and GSI high-level control system: MPS, Quench and FPA (Fast Power Abort) respectively. It is important to note that CIBm module generates fast power abort signal for all parts of energy extraction system: FPA_ICM#1, FPA_ICM#2.
Control and Interface Board slave

CIBs digitizes analog signal such as, output voltage, output current as well as receives interlocks from protection module and transmits output digital signals to the protection module. All interlocks are summarized to form the overall protection signal PS tripline.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC, 16bit, SAR, 200kSp</td>
<td>8x bipolar channels (+/- 10V)</td>
</tr>
<tr>
<td>I/O registers</td>
<td>4x input / 4x output</td>
</tr>
<tr>
<td>Trip lines</td>
<td>PS tripline</td>
</tr>
<tr>
<td>Communication</td>
<td>1x CanBus</td>
</tr>
</tbody>
</table>
**Power Supply trip line:**

- CIBs module and CIBm module are looped by overall protection PS tripline.
- This loop consists of current source placed on the side of CIBm module and phototransistors
- Can break the loop in case of any interlock will appear.
CIBm module collects abort signals from several systems. In case of any of abort signals detected PS tripline will be immediately braked and signal to open the breakers of energy extraction system will be sent to ICM#1 - #4. It also works in other way around. In case of interlock in energy extraction system or in power supply machine protection system and GSI high level control system will be informed immediately.
**Fast Power Abort (FPA)**

Triggers to provide the high redundancy realize fast power abort distribution logic.
Energy extraction system for redundancy consists of two breakers; therefore, two undependable ICM modules to follow the redundancy principle control two breakers. First ICM controls Breaker A, and second – Breaker B. Digitizing of analog signals is shared between to ICM modules.

ICM#1 controls Breaker A by four digital signals: Zero_release_A, Pulse_release_A, Motor_ON_A, Motor_OFF_A. Furthermore, ICM#1 receives statuses of Breaker A, digitizes current sharing analog signals and monitors the voltage of the buffer capacitor on the Breaker A driver board (U_cap_A).

ICM#2 controls Breaker B similar to ICM#1, but digitizes other analog signals: temperature of the dump resistor, energy extraction system voltage drop, temperature in the rack and monitors the voltage of the buffer capacitor on the Breaker B driver board.

Connection between ICM#1, ICM#2 and ACU is provided by USI interface. ICM transmits status of the Breakers to CIBm board and receives Fast Power Abort signal.


Energy Extraction System Control electronics

![Diagram of Energy Extraction System Control electronics](image)

- **ICM #1**
  - USI Motor _close_
  - Motor_open
  - CIBm
  - Breaker #A
  - statuses
  - ACU
  - To Breaker #A driver
  - Analog signals from EES

- **ICM #2**
  - USI Motor _close_
  - Motor_open
  - CIBm
  - Breaker #B
  - statuses
  - ACU
  - To Breaker #B driver
  - Analog signals from EES
**Status**

**Current status**

- PDR – done.
- CDR – done.
- FDR (including risk assessment) – done.
- Dump resistor and most of the hardware are in the workshop.
- We are in process of the components and key elements ordering.

**Notes:** According to FDR we supposed to use the current sources VCH1300, but due to the number of reasons we will use the commercial modules TDK-Lambda, Genesys+. It will take a minimum of changes in the drawings and will not give the impact to the manufacturing. Engineering change request is on the way.
Thanks for Your Attention!