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## R&D ERL: Power Supplies

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Collider Accelerator Department  
**Brookhaven National Laboratory**

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# R&D ERL: Power Supplies

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R&D ERL – Power Supplies  
R. Lambiase  
December 18, 2009

A magnet power supply system has been developed to meet the field requirements of the ERL in a compact and cost effective fashion.

Design Considerations

The magnet assemblies used in the ERL consist of one or more windings on a common core. Each of the windings represents a separate magnet load for the power supply. As the ERL is operated in a DC fashion, interaction between the windings is not a concern.

Appendix A lists all the magnet assemblies by sector. Each coil is listed by name and model. The model corresponds to a set of electrical and magnet parameters as established by the magnet subsystem.

Some of the coils are connected in series. The connection scheme, plus cabling provides the electrical load characteristics. The load information, plus the operating current, and the stability define the power supply requirements.

Power Supply Listing

All of the magnet power supply requirements for ERL can be satisfied by five different models. The capsule specifications and quantities are shown in Table 1 below.

Model	Voltage, Volts	Current, Amps	Precision, ppm	Quantity
UD320A35V, IE Power	35	320	100	1
Shim Amplifier 892, Danfysik	15	10	100	34
BOP 50-20GL, Kepco	50	20	100	5
MCOR12 / 2A, BiRa	25	2	1000	32
MCOR12 / 6A, BiRa	25	6	1000	6

With the exception of the UD320A35V unit, all models are bipolar, even though not all loads require bipolar operation. But, by using standard off-the-shelf units, development costs were minimized.

Appendix B lists each power supply, by model, with its magnet load.

UD320A35V, IE Power

Ratings: 320A, 35V, 100ppm  
Qty: 1

This supply is used to power the six main dipoles in series. It can be seen as the cabinet on the left in Figure 1.

This supply is a thyristor controlled supply using the same design, but slightly different rating, as the 77 medium range power supplies built for the SNS at ORNL.

This supply is controlled by a standard BNL Power Supply Interface (PSI).

BOP 50-20GL, Kepco

Ratings: 50V, 20A, 100ppm  
Qty: 5

This supply is used where higher voltage is needed, typically where there are more than one coil in series as a load. All five units can be seen mounted in the cabinet on the right in Figure 1.

These switch mode supplies are a high precision version of the standard Kepco high power BOP. The extra precision is obtained by closing the current loop around a zero flux current sensor (ZFCT) and adding additional output filtering to reduce the output ripple to a level consistent with the higher precision.

Control of these supplies will be by RS-232.



**Figure 1. IE Power & Kepco Supplies**

Shim Amplifier 892, Danfysik

Ratings: 10A, 15V, 100ppm  
Qty: 34

All 34 supplies, plus two spares, are shown in Figure 2. Each crate consists of a bulk power supply and six regulators. Each regulator has a front end switching pre-regulator followed by a linear H bridge. The high stability is maintained by an on-board ZFCT.

These power supplies are scaled down versions of the 20A, 70V low field correctors designed for the ORNL SNS. By reducing the power, these were able to be packaged in a compact configuration, and used to power shim windings on MRI machines. It's also very useful for us to have this many high precision power supplies in a small volume.

Each channel can be individually manually controlled by the controller seen at the top of the left cabinet. It has the capability to address and control up to 256 regulators.

In operation, these supplies will be controlled by a RS-485 line.



**Figure 2. Danfysik Power Supplies**



### MCOR12 / 2A, BiRa

Rating: 2A, 25V, 1000ppm  
Qty: 36

### MCOR12 / 6A, BiRa

Rating: 2A, 25V, 1000ppm  
Qty: 36

These magnet power supplies are shown in Figure 3. The 32 regulators rated at 2A each in two crates in the left cabinet, and the six regulators rated at 6A each are in the crate in the right cabinet.

This magnet corrector power supply system was designed at SLAC, and built to their specification by BiRa.

Each crate contains one analog interface board and up to 16 MCOR12 regulator cards that can be configured as 2A, 6A, or 12A by means of a programming daughter board.

These regulators are powered by a commercial unipolar power supply. In our application, these are Genesys 30V, 50A units.

Completing the system is a 2U blower assembly which goes between the bulk power supply and the crate. It draws air from the front panel through a filter and directs it up between the cards.

Each regulator accepts (via the interface card) one analog current set point, and returns one analog current read back. These signals will come from VME DACs and ADCs in the control crate. In addition, each crate has a group interlock, and group status.

An RS-232 digital interface, which includes the ADC and DAC functions is under development at SLAC, but is not completed at this time.



**Figure 3. BiRa Power Supplies**

## Rack Layout

The magnet power supplies are all located in a room above the transmitter water room. The arrangement of racks is shown in Figure 4.

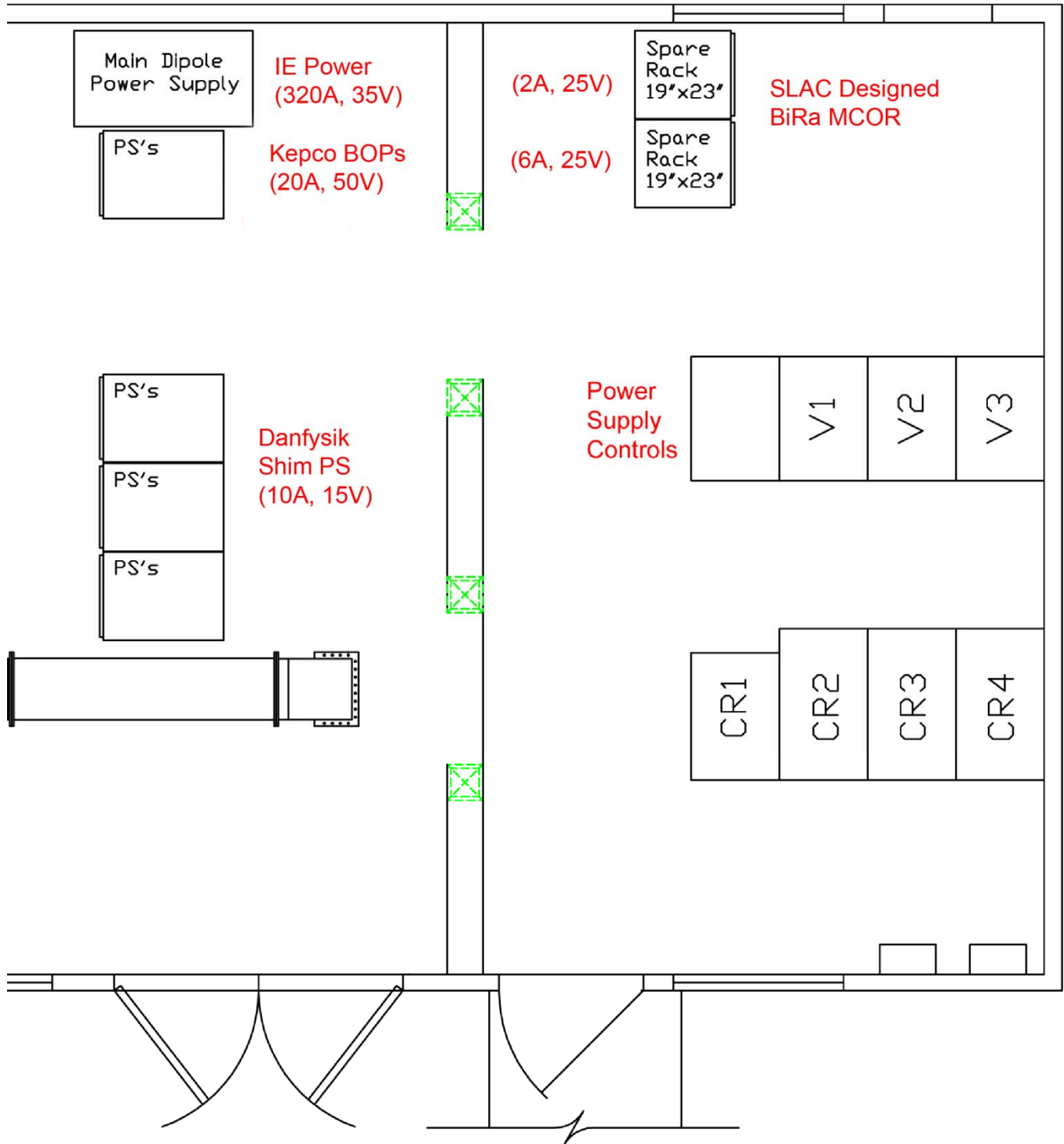


Figure 4. Power Supply Rack Layout



### Construction Status

All of the magnet power supplies have been delivered, and are nearly fully installed mechanically. Work will continue with installing cables for AC power to the equipment, DC cables from the equipment to the magnets, and control cables from the control system to the power supplies.

This work should be completed by February 2010.

### Commissioning Plans

All of the power supplies have been tested at the factory, and there are no technical complexities to commissioning these supplies. The control interface design will be tested prior to the actual magnet loads being connected and the final system testing will proceed as the magnet loads are connected.

## Appendix A

### Magnet Configuration by Sector

#### Sector: 1

Magnet: 1 - 1 : High Temp SC solenoid

Assembly Name: ELS1.1                      Assembly Model: 10S10HTS

Coil Name: ELS1.1                      Coil Name: 10S10HTS

#### Sector: 2

Magnet: 2 - 1 : Air coils around 6-way cross

Assembly Name: ELC2.1                      Assembly Model: 5D10

Coil Name: ELC2.1CH                      Coil Name: 5DH10

Coil Name: ELC2.1CV                      Coil Name: 5DV10

Coil Name: ELS2.1                      Coil Name: 11S10

#### Sector: 3

Magnet: 3 - 1 : 15 degree combined function

Assembly Name: ELD3.1                      Assembly Model: 7C15

Coil Name: ELD3.1                      Coil Name: 7CD15

Coil Name: ELD3.1CH                      Coil Name: 7CDHT15

Coil Name: ELD3.1Q                      Coil Name: 7CQ15

Coil Name: ELD3.1X                      Coil Name: 7CX15

Magnet: 3 - 2 : 30 degree combined function

Assembly Name: ELD3.2                      Assembly Model: 7C30

Coil Name: ELD3.2                      Coil Name: 7CD30

Coil Name: ELD3.2CH                      Coil Name: 7CDHT30

Coil Name: ELD3.2Q                      Coil Name: 7CQ30

Coil Name: ELD3.2X                      Coil Name: 7CX30

Magnet: 3 - 3 : 15 degree combined function

Assembly Name: ELD3.3                      Assembly Model: 7C15

Coil Name: ELD3.3                      Coil Name: 7CD15

Coil Name: ELD3.3CH                      Coil Name: 7CDHT15

Coil Name: ELD3.3Q                      Coil Name: 7CQ15

Coil Name: ELD3.3X                      Coil Name: 7CX15

Magnet: 3 - 4 : 30 degree combined function

Assembly Name: ELD3.4                      Assembly Model: 7C30

Coil Name: ELD3.4                      Coil Name: 7CD30

Coil Name: ELD3.4CH                      Coil Name: 7CDHT30

Coil Name: ELD3.4Q                      Coil Name: 7CQ30

Coil Name: ELD3.4X                      Coil Name: 7CX30

**Sector:4**

Magnet: 4 - 1 : Injection line solenoid  
Assembly Name: ELS4.1 Assembly Model: 11S10  
Coil Name: ELS4.1 Coil Name: 11S10

Magnet: 4 - 2 : Injection line solenoid  
Assembly Name: ELS4.2 Assembly Model: 11S10  
Coil Name: ELS4.2 Coil Name: 11S10

Magnet: 4 - 3 : Extraction line solenoid  
Assembly Name: ELS4.3 Assembly Model: 11S10  
Coil Name: ELS4.3 Coil Name: 11S10

Magnet: 4 - 4 : Extraction line solenoid  
Assembly Name: ELS4.4 Assembly Model: 11S10  
Coil Name: ELS4.4 Coil Name: 11S10

**Sector: 5**

Magnet: 5 - 1 : 1st Extraction dipole  
Assembly Name: ELD5.1 Assembly Model: 6D20  
Coil Name: ELD5.1 Coil Name: 6D20  
Coil Name: ELD5.1CH Coil Name: 6DT20  
Coil Name: ELS5.1 Coil Name: 11S10

Magnet: 5 - 2 : Compensating chicane  
Assembly Name: ELD5.2 Assembly Model: 6D40  
Coil Name: ELD5.2 Coil Name: 6D40  
Coil Name: ELD5.2CH Coil Name: 6DT40  
Coil Name: ELS5.2 Coil Name: 11S10

Magnet: 5 - 3 : Compensating chicane  
Assembly Name: ELD5.3 Assembly Model: 6D20  
Coil Name: ELD5.3 Coil Name: 6D20  
Coil Name: ELD5.3CH Coil Name: 6DT20

**Sector: 6**

Magnet: 6 - 1 : 60 degree dipole, 20 cm radius  
Assembly Name: ELD6.1 Assembly Model: 3D60  
Coil Name: ELD6.1 Coil Name: 3D60  
Coil Name: ELD6.1CH Coil Name: 3DT60  
Coil Name: ELQ6.1 Coil Name: 6Q12

Magnet: 6 - 2 : Regular quadrupole  
Assembly Name: ELQ6.2 Assembly Model: 6Q12  
Coil Name: ELQ6.2 Coil Name: 6Q12  
Coil Name: ELQ6.2CV Coil Name: 6QTV12

Magnet: 6 - 3 : Regular quadrupole  
Assembly Name: ELQ6.3 Assembly Model: 6Q12  
Coil Name: ELQ6.3 Coil Name: 6Q12

**Sector: 7**

Magnet: 7 - 1 : 60 degree dipole, 20 cm radius

Assembly Name: ELD7.1	Assembly Model: 3D60
Coil Name: ELD7.1	Coil Name: 3D60
Coil Name: ELD7.1CH	Coil Name: 3DT60
Coil Name: ELQ7.1	Coil Name: 6Q12
Coil Name: ELQ7.1CH	Coil Name: 6QTH12

Magnet: 7 - 2 : Regular quadrupole

Assembly Name: ELQ7.2	Assembly Model: 6Q12
Coil Name: ELQ7.2	Coil Name: 6Q12
Coil Name: ELQ7.2CV	Coil Name: 6QTV12

Magnet: 7 - 3 : Regular quadrupole

Assembly Name: ELQ7.3	Assembly Model: 6Q12
Coil Name: ELQ7.3	Coil Name: 6Q12

**Sector: 8**

Magnet: 8 - 1 : 60 degree dipole, 20 cm radius

Assembly Name: ELD8.1	Assembly Model: 3D60
Coil Name: ELD8.1	Coil Name: 3D60
Coil Name: ELD8.1CH	Coil Name: 3DT60
Coil Name: ELQ8.1	Coil Name: 6Q12

Magnet: 8 - 2 : Regular quadrupole

Assembly Name: ELQ8.2	Assembly Model: 6Q12
Coil Name: ELQ8.2	Coil Name: 6Q12
Coil Name: ELQ8.2CV	Coil Name: 6QTV12

Magnet: 8 - 3 : Regular quadrupole

Assembly Name: ELQ8.3	Assembly Model: 6Q12
Coil Name: ELQ8.3	Coil Name: 6Q12
Coil Name: ELQ8.3CH	Coil Name: 6QTH12

**Sector: 9**

Magnet: 9 - 1 : Regular quadrupole

Assembly Name: ELQ9.1	Assembly Model: 6Q12
Coil Name: ELQ9.1	Coil Name: 6Q12

Magnet: 9 - 2 : Regular quadrupole

Assembly Name: ELQ9.2	Assembly Model: 6Q12
Coil Name: ELQ9.2	Coil Name: 6Q12
Coil Name: ELQ9.2CV	Coil Name: 6QTV12

**Sector: 10**

Magnet: 10 - 1 : Regular quadrupole

Assembly Name: ELQ10.1	Assembly Model: 6Q12
Coil Name: ELQ10.1	Coil Name: 6Q12

Magnet: 10 - 2 : Regular quadrupole

Assembly Name: ELQ10.2	Assembly Model: 6Q12
Coil Name: ELQ10.2	Coil Name: 6Q12

Coil Name: ELQ10.2CH

Coil Name: 6QTH12

**Sector: 11**

Magnet: 11 - 1 : Regular quadrupole

Assembly Name: ELQ11.1      Assembly Model: 6Q12

Coil Name: ELQ11.1      Coil Name: 6Q12

Magnet: 11 - 2 : Regular quadrupole

Assembly Name: ELQ11.2      Assembly Model: 6Q12

Coil Name: ELQ11.2      Coil Name: 6Q12

Coil Name: ELQ11.2CH      Coil Name: 6QTH12

**Sector: 12**

Magnet: 12 - 1 : 60 degree dipole, 20 cm radius

Assembly Name: ELD12.1      Assembly Model: 3D60

Coil Name: ELD12.1      Coil Name: 3D60

Coil Name: ELD12.1CH      Coil Name: 3DT60

Coil Name: ELQ12.1      Coil Name: 6Q12

Magnet: 12 - 2 : Regular quadrupole

Assembly Name: ELQ12.2      Assembly Model: 6Q12

Coil Name: ELQ12.2      Coil Name: 6Q12

Coil Name: ELQ12.2CV      Coil Name: 6QTV12

**Sector: 13**

Magnet: 13 - 1 : 60 degree dipole, 20 cm radius

Assembly Name: ELD13.1      Assembly Model: 3D60

Coil Name: ELD13.1      Coil Name: 3D60

Coil Name: ELD13.1CH      Coil Name: 3DT60

Coil Name: ELQ13.1      Coil Name: 6Q12

Coil Name: ELQ13.1CH      Coil Name: 6QTH12

Magnet: 13 - 2 : Regular quadrupole

Assembly Name: ELQ13.2      Assembly Model: 6Q12

Coil Name: ELQ13.2      Coil Name: 6Q12

Coil Name: ELQ13.2CV      Coil Name: 6QTV12

Magnet: 13 - 3 : Regular quadrupole

Assembly Name: ELQ13.3      Assembly Model: 6Q12

Coil Name: ELQ13.3      Coil Name: 6Q12

**Sector: 14**

Magnet: 14 - 1 : 60 degree dipole, 20 cm radius

Assembly Name: ELD14.1      Assembly Model: 3D60

Coil Name: ELD14.1      Coil Name: 3D60

Coil Name: ELD14.1CH      Coil Name: 3DT60

Coil Name: ELQ14.1      Coil Name: 6Q12

Magnet: 14 - 2 : Regular quadrupole

Assembly Name: ELQ14.2      Assembly Model: 6Q12

Coil Name: ELQ14.2      Coil Name: 6Q12

Coil Name: ELQ14.2CV      Coil Name: 6QTV12

Magnet: 14 - 3 : Regular quadrupole

Assembly Name: ELQ14.3      Assembly Model: 6Q12

Coil Name: ELQ14.3      Coil Name: 6Q12

Coil Name: ELQ14.3CH      Coil Name: 6QTH12

**Sector:15**

Magnet: 15 - 1 : Small compensating dipole

Assembly Name: ELD15.1      Assembly Model: 3D2

Coil Name: ELD15.1      Coil Name: 3D2

Coil Name: ELQ15.1      Coil Name: 3Q12

Magnet: 15 - 2 : Small compensating dipole

Assembly Name: ELD15.2      Assembly Model: 3D2

Coil Name: ELD15.2      Coil Name: 3D2

Coil Name: ELQ15.2      Coil Name: 3Q12

**Sector: 16**

Magnet: 16 - 1 : Corrector in extraction line

Assembly Name: ELC16.1      Assembly Model: 5D10

Coil Name: ELC16.1CH      Coil Name: 5DH10

Coil Name: ELC16.1CV      Coil Name: 5DV10

Coil Name: ELD16.1      Coil Name: 6D30

Coil Name: ELS16.1      Coil Name: 10S10

Magnet: 16 - 2 : Driving to Beam Dump Solenoid

Assembly Name: ELS16.2      Assembly Model: 10S10

Coil Name: ELS16.2      Coil Name: 10S10

Magnet: 16 - 3 : Driving to Beam Dump Solenoid

Assembly Name: ELS16.3      Assembly Model: 10S10

Coil Name: ELS16.3      Coil Name: 10S10

Magnet: 16 - 4 : Driving to Beam Dump Solenoid

Assembly Name: ELS16.4      Assembly Model: 10S10

Coil Name: ELS16.4      Coil Name: 10S10



## Appendix B Magnet Circuits by Power Supply Model

### UD320A35V, IE Power

1 . PS_ELDMain	
<i>ELD8.1</i>	3D60
<i>ELD12.1</i>	3D60
<i>ELD14.1</i>	3D60
<i>ELD6.1</i>	3D60
<i>ELD13.1</i>	3D60
<i>ELD7.1</i>	3D60

### Shim Amplifier 892, Danfysik

1 . PS_ELD15.1	
<i>ELD15.1</i>	3D2
2 . PS_ELD15.2	
<i>ELD15.2</i>	3D2
3 . PS_ELD16.1	
<i>ELD16.1</i>	6D30
4 . PS_ELD3.1	
<i>ELD3.1</i>	7CD15
5 . PS_ELD3.2	
<i>ELD3.2</i>	7CD30
6 . PS_ELD3.3	
<i>ELD3.3</i>	7CD15
7 . PS_ELD3.4	
<i>ELD3.4</i>	7CD30
8 . PS_ELQ10.1	
<i>ELQ10.1</i>	6Q12
9 . PS_ELQ10.2	
<i>ELQ10.2</i>	6Q12
10 . PS_ELQ11.1	
<i>ELQ11.1</i>	6Q12
11 . PS_ELQ11.2	
<i>ELQ11.2</i>	6Q12
12 . PS_ELQ12.1	
<i>ELQ12.1</i>	6Q12
13 . PS_ELQ12.2	
<i>ELQ12.2</i>	6Q12
14 . PS_ELQ13.1	
<i>ELQ13.1</i>	6Q12
15 . PS_ELQ13.2	
<i>ELQ13.2</i>	6Q12
16 . PS_ELQ13.3	
<i>ELQ13.3</i>	6Q12
17 . PS_ELQ14.1	
<i>ELQ14.1</i>	6Q12
18 . PS_ELQ14.2	
<i>ELQ14.2</i>	6Q12
19 . PS_ELQ14.3	
<i>ELQ14.3</i>	6Q12

20 . PS_ELQ15.1	
<i>ELQ15.1</i>	3Q12
21 . PS_ELQ15.2	
<i>ELQ15.2</i>	3Q12
22 . PS_ELQ6.1	
<i>ELQ6.1</i>	6Q12
23 . PS_ELQ6.2	
<i>ELQ6.2</i>	6Q12
24 . PS_ELQ6.3	
<i>ELQ6.3</i>	6Q12
25 . PS_ELQ7.1	
<i>ELQ7.1</i>	6Q12
26 . PS_ELQ7.2	
<i>ELQ7.2</i>	6Q12
27 . PS_ELQ7.3	
<i>ELQ7.3</i>	6Q12
28 . PS_ELQ8.1	
<i>ELQ8.1</i>	6Q12
29 . PS_ELQ8.2	
<i>ELQ8.2</i>	6Q12
30 . PS_ELQ8.3	
<i>ELQ8.3</i>	6Q12
31 . PS_ELQ9.1	
<i>ELQ9.1</i>	6Q12
32 . PS_ELQ9.2	
<i>ELQ9.2</i>	6Q12
33 . PS_ELS1.1	
<i>ELS1.1</i>	10S10HTS
34 . PS_ELS2.1	
<i>ELS2.1</i>	11S10

**MCOR12 / 6A, BiRa**

1 . PS_ELD12.1CH <i>ELD12.1CH</i>	3DT60
2 . PS_ELD13.1CH <i>ELD13.1CH</i>	3DT60
3 . PS_ELD14.1CH <i>ELD14.1CH</i>	3DT60
4 . PS_ELD6.1CH <i>ELD6.1CH</i>	3DT60
5 . PS_ELD7.1CH <i>ELD7.1CH</i>	3DT60
6 . PS_ELD8.1CH <i>ELD8.1CH</i>	3DT60

**MCOR12 / 2A, BiRa**

1 . PS_ELC16.1CH <i>ELC16.1CH</i>	5DH10
2 . PS_ELC16.1CV <i>ELC16.1CV</i>	5DV10
3 . PS_ELC2.1CH <i>ELC2.1CH</i>	5DH10
4 . PS_ELC2.1CV <i>ELC2.1CV</i>	5DV10
5 . PS_ELD3.1CH <i>ELD3.1CH</i>	7CDHT15
6 . PS_ELD3.1Q <i>ELD3.1Q</i>	7CQ15
7 . PS_ELD3.1X <i>ELD3.1X</i>	7CX15
8 . PS_ELD3.2CH <i>ELD3.2CH</i>	7CDHT30
9 . PS_ELD3.2Q <i>ELD3.2Q</i>	7CQ30
10 . PS_ELD3.2X <i>ELD3.2X</i>	7CX30
11 . PS_ELD3.3CH <i>ELD3.3CH</i>	7CDHT15
12 . PS_ELD3.3Q <i>ELD3.3Q</i>	7CQ15
13 . PS_ELD3.3X <i>ELD3.3X</i>	7CX15
14 . PS_ELD3.4CH <i>ELD3.4CH</i>	7CDHT30
15 . PS_ELD3.4Q <i>ELD3.4Q</i>	7CQ30
16 . PS_ELD3.4X <i>ELD3.4X</i>	7CX30
17 . PS_ELD5.1CH <i>ELD5.1CH</i>	6DT20
18 . PS_ELD5.2CH <i>ELD5.2CH</i>	6DT40

19 . PS_ELD5.3CH <i>ELD5.3CH</i>	6DT20
20 . PS_ELQ10.2CH <i>ELQ10.2CH</i>	6QTH12
21 . PS_ELQ11.2CH <i>ELQ11.2CH</i>	6QTH12
22 . PS_ELQ12.2CV <i>ELQ12.2CV</i>	6QTV12
23 . PS_ELQ13.1CH <i>ELQ13.1CH</i>	6QTH12
24 . PS_ELQ13.2CV <i>ELQ13.2CV</i>	6QTV12
25 . PS_ELQ14.2CV <i>ELQ14.2CV</i>	6QTV12
26 . PS_ELQ14.3CH <i>ELQ14.3CH</i>	6QTH12
27 . PS_ELQ6.2CV <i>ELQ6.2CV</i>	6QTV12
28 . PS_ELQ7.1CH <i>ELQ7.1CH</i>	6QTH12
29 . PS_ELQ7.2CV <i>ELQ7.2CV</i>	6QTV12
30 . PS_ELQ8.2CV <i>ELQ8.2CV</i>	6QTV12
31 . PS_ELQ8.3CH <i>ELQ8.3CH</i>	6QTH12
32 . PS_ELQ9.2CV <i>ELQ9.2CV</i>	6QTV12

**BOP 50-20GL, Kepco**

1 . PS_ELD5.1-3 <i>ELD5.3</i>	6D20
<i>ELD5.2</i>	6D40
<i>ELD5.1</i>	6D20
2 . PS_ELS16.1-4 <i>ELS16.1</i>	10S10
<i>ELS16.2</i>	10S10
<i>ELS16.3</i>	10S10
<i>ELS16.4</i>	10S10
3 . PS_ELS4.1-2 <i>ELS4.2</i>	11S10
<i>ELS4.1</i>	11S10
4 . PS_ELS4.3-4 <i>ELS4.4</i>	11S10
<i>ELS4.3</i>	11S10
5 . PS_ELS5.1-2 <i>ELS5.1</i>	11S10
<i>ELS5.2</i>	11S10