PEP-II Magnet Power Conversion Systems[*]

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Abstract

The paper presents the cooperative design efforts of LBL, LLNL and SLAC on the Magnet Power Conversion Systems for PEP-II. The systems include 900 channels of correction magnets bipolar power supplies and 400 unipolar power supplies in the range of 5 to 500 kW. We show the decision process and technical considerations influencing the choice of power supply technologies employed. We also show the development of specifications that take maximum advantage of both the available resources and existing facilities while, at the same time, satisfying tight constraints for cost control, scheduling and coordination of different working groups. Switchmode power conversion techniques will be used extensively in these systems, from the corrector supplies to the largest units if the dynamic performance specifications demand it. General systems descriptions for each of the power supply ranges and for a new common control systems interface are included.

WORK DIVISION - A TALE OF THREE LABS

The PEP-II B factory accelerator complex is being built at SLAC as a cooperative effort among the three DOE laboratories in the SF Bay area: LBL, SLAC and LLNL. The Magnet Power Conversion is one of the areas that because of its relatively large size, diversity of systems and technical complexity requires a close cooperation among the three technical groups involved in the design and construction of this part of the machine.

To implement this kind of cooperation an agreement was achieved very early on in the process by the engineering group leaders, based on the optimal utilization of the talent pool, recent experience and hardware developments at each one of the laboratories, facilities and other technical resources and the project schedule. Of particular concern were the overall cost, the expected performance of the systems and their maintenability.

One important issue that influenced the initial decisions on work division was the need to maximize the uniformity of systems (i.e. all power supplies of a similar power level must be of the same technology and manufacture) to reduce the impact of personnel training in new systems and the cost of the stock of spare components and redundant on-line systems. For this reason the division of work for the Power Conversion Systems splits along different lines than the overall machine division of work which goes along ring lines. SLAC Power Conversion Department carries the leadership in the generation of the specifications for the systems since, by the end of the project, SLAC will be the laboratory operating the machine.

Resolution	
Setting & readback	18 bits
Accuracy (1 yr)	
Setting & readback	.01% FSR
Long term stability (10 C span)	
Single channel P.S.	.005% FSR
Periodic deviations (60 Hz & harm., LF noise)	
Single channel PS	.01% FSR
Random deviations (AC line changes)	
SCR P.S.(w/fast V feedback)	<.05% FSR
Switching P.S	<.01% FSR

Table 1- P.S. & controller/interface performance specs.

SYSTEMS DESCRIPTION

PEP-II is being built reusing the old tunnel and a large portion of the equipment (cable plant, power distribution, civil construction) of PEP-I (Ref. 4). PEP-II will need 21 power supply systems for the large strings (Group III, LLNL), circuits for magnets distributed around the 2 Km circumference of the machine. It will also need 244 medium power power supplies (Group II, SLAC) to drive individual magnets and short strings, composed of two or three series magnets in relatively near locations, and 37 power supplies of medium to high power (Group II, LBL), mostly one or two of a kind systems. In addition it requires somewhere between 900- 1000 power supply channels for correctors and trim coils (LBL).

POWER SUPPLY SYSTEM ENGINEERING

The sytem design uses two general architectures, one for multiple channel power supplies, employed for the small drivers for correctors and trims, and the single channel, for everything else. The single channel power supply system is a design very similar to units in use at SLAC (Ref 1). It consists of a voltage regulated /voltage controlled power supply as its power train, driven by a current regulation loop with a high stability (<2ppm/C) error amplifier. The current regulation loop workpoint is set by an analog reference generated by the control system interface. Current is measured by two identical ZFTs (Zero Flux Transductor) integrated type (magnetic head

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and electronics on the same package) transductors. One of the ZFTs is used for the control of the magnet current through the current regulation loop, and the other one as an independent diagnostic readback. The system has a single fault ground fault detector. The multiple channel systems have similar features, in different implementations, as described elsewhere in another paper in the Proceedings of this Conference (Ref 3).

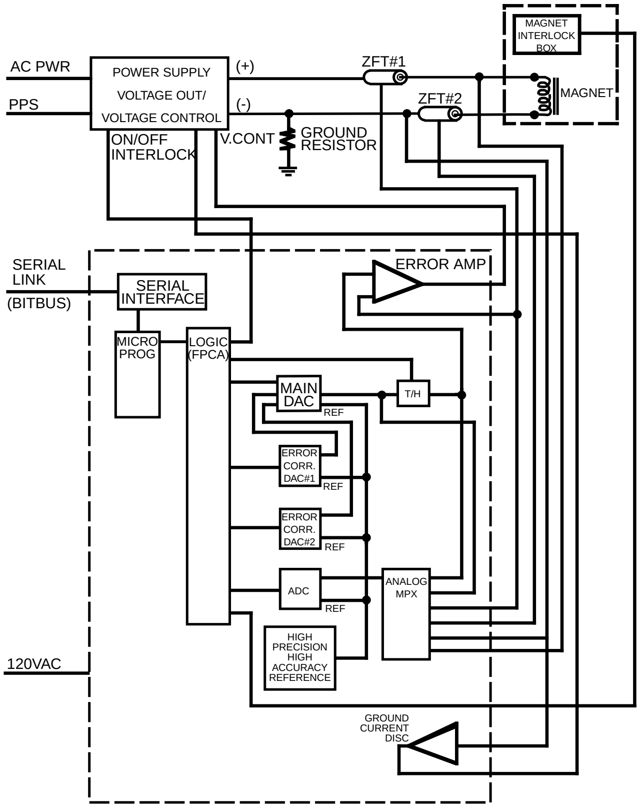

Fig . 1. Power supply system block diagram

FACTORS INFLUENCING THE CHOICES ON POWER SUPPLY TECHNOLOGIES

Many factors are being considered to arrive at solutions of the technical problems presented by the PEP-II machine design specifications. The individual performance issues were initially evaluated, including stability, accuracy and tolerances for periodic and random deviations. Overall performance issues such as availability, initial and operating system costs and MTTR are then weighed. Included under cost are the solutions that allow to use and recycle existing components of PEP-I such as the cable plant (AC & DC) and the power distribution systems (transformers, switchgear) that will be refurbished and reused. The power distribution decisions were for AC distribution, because of the simplicity of the protection systems and easier compliance with safety regulations. The exception are the large string power supplies, where existing DC distribution systems were recycled. Other influences on the technical solutions are EMC concerns, both EMI generation and susceptibility, and power supply efficiency.

CONTROL SYSTEM INTERFACES

A new control system interface/error amplifier/ power supply controller will be used in the power conversion systems for PEP-II. Its design will take advantage of the advances in digital technology since the early 80’s when the standards and the hardware for the interfaces currently in use at SLAC were designed, and of the experience with high stability intermediate units developed more recently (Ref. 2). The interface is connected to the control system by means of a digital serial line (Bitbus). A microprocessor is used as the communications controller and as the intelligence for the power supply controller for functions such as data I/O, diagnostics routines and ramping. The use in the controller unit of an intelligent programmable processor allows for a large improvement in the performance of the data conversion components. An internal calibration process, running while the supply operates, makes possible the transfer of the accuracy and precision of a high quality reference to the DAC and ADC performance. The process corrects for offset, gain and linearity imperfections and drifts for the DAC and offset and gain for the ADC. This allows the use of data conversion units of less stringent specifications (read less expensive).

DESCRIPTION OF THE MAJOR GROUPS OF POWER SUPPLIES

Power supplies for correctors and trim coils

This systems are described in another paper, by T. Jackson and G. Leyh, these Proceedings (Ref 3).

Power supplies for medium power individual magnets and small strings (Group I)

This is the range of individual power supplies with the largest number of power supplies. The system engineering is assigned to SLAC. It was decided early on to use a single type of technology for the whole range, based on similar requirements for performance and with the goal of simplifying maintenance procedures, reducing spares stock, personnel training and MTTR. The decision on which type of power supply technology to be used, based mostly on performance, costs, and past experience, is for the use of commercially available, standard model switchmode power supplies with AC power input. A procurement specification is under review. The objective set for this specification is to characterize the requirements for the range of power supplies, identifying clearly those parameters that need tight specifications, while leaving other parameters more open to widen the field of possible vendors.

Power Supplies for individual magnets, medium high and high power (Group II).

For this group, the technology decision does not need to be unified, since there are, with few exceptions, one or two of each kind, and rather dissimilar in their specifications. The unit price for power supply is higher, because of the higher power, and a case by case decision is to be made in each case, by performance and cost. The system engineering is identical to those P.S. in group I (Fig. 1)

Power Supplies for Large Magnet Strings(Group III).

PEP II has 21 circuits of large string series-connected magnets in the two rings, 16 for HER, and 5 for LER. Circuits are for the bend dipoles, focus and defocus quadrupoles, focus and defocus sextupoles, and many special quadrupoles. The largest strings are the dipoles, 192 (HER) and 200 (LER).

Total maximum operating power is 4300 kW, 2400 kW (56 %) for HER and 1900 kW (44 %) for the LER strings.

Power supply architecture is similar to that of PEP I (Ref.4) : bulk dc P.S.s drive several buck-type dc-dc chopper/ converters (Fig. 2). In the bulk P.S.s two transformers, associated switchgear and half-controlled rectifiers, provide positive and negative 600 Vdc for the individual string circuit dc-dc converters with low inrush currents and fast fault protection . HER and LER strings have separate circuit breakers and rectifiers for operational flexibility.

The current control for each magnet string is achieved by using insulated-gate-bipolar transistors (IGBTs) chopper/ converters. The 200 kW modules' output is 400 A, at either + or - 500 Vdc, with extensive differential and common-mode filtering, and can be connected in series and in parallel.

The string voltage limit is 1000 Vdc, defined by system insulation, and can be achieved using positive and negative dc-dc chopper/converter modules in series. Magnet strings which require more than 1000 Vdc must be divided. The HER bend magnet string will need three modules in parallel for 890 A, and in order not to exceed the 1000 V limit, it also must be divided into two strings of 96 magnets and 690 V each. A total of 12 chopper/converters is used. The LER bend magnet string also requires splitting and has two strings of 100 magnets at 745 A and 990 V each, using a total of 8 chopper/converters. Four of the quadrupole strings are below 400 A but need two modules each because the voltages are above 500 V. The other 15 circuits require only one module since currents and voltages are all below 400 A and 500 V.

The power circuit of the dc-dc converter module is shown in Fig. 3. It is based on a design by an engineering team at LLNL (Ref.5). Two 600 A, 1200 V IGBTs are alternately gated at 10 kHz for an effective 20 kHz internal frequency. Snubbers networks across the IGBTs reduce turnon losses and clamp the voltage during turnoff. IGBTs and diodes are mounted on a water-cooled aluminum heat sink. The "box-in-box" construction and the common-mode filters at the input and output control EMI. The IGBTs are controlled using commercial gate drivers linked by fiber optics to a commercial current-mode PWM controller. The duty cycle of the IGBTs varies the average output voltage in response to a voltage setpoint. A "breadboard" version of the dc-dc converter power circuit has operated successfully at 200 kW .

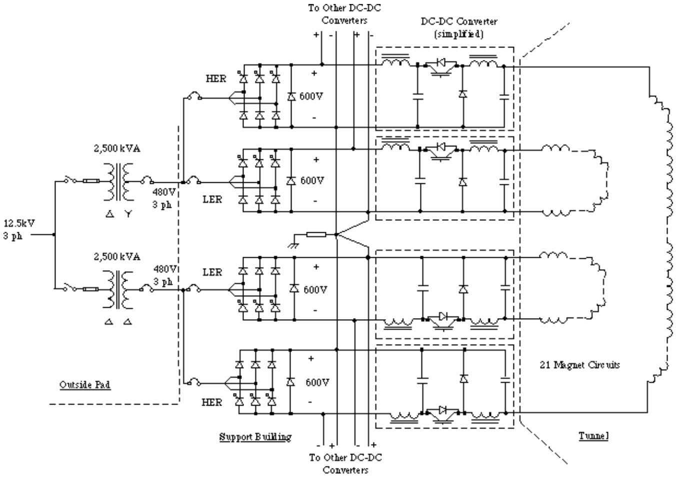

Fig. 2. String magnet power supplies. Simplified power circuit.

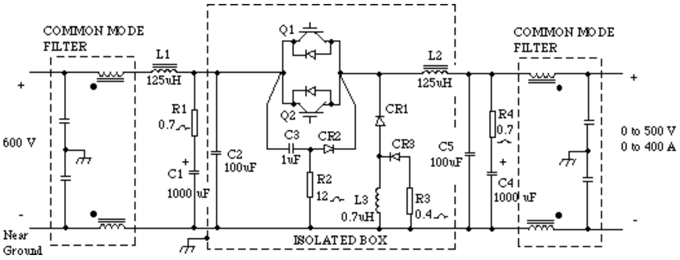

Fig. 3. 200 kW dc-dc converter power circuit.

1) M. Berndt, J. McNair, "DC Magnet Power Supplies for the FFTB at SLAC", San Francisco 1993, IEEE Nuclear Science Symposium.

2) M. Berndt, J. McNair, A.H. Saab, "The Design of a Precision Current Regulation Power Supply Controller", San Francisco 1993, IEEE Nuclear Science Symposium.

3) G.E.Leyh, A.R. Donaldson, L.T. Jackson, "A Multi-channel Corrector Magnet Controller", Dallas 1995, IEEE PAC.

4) L.T. Jackson, "Design and Performance of PEP DC Power Systems", IEEE Transactions on Nuclear Science, Vol. NS-28, No3, pp 2737-2741, June 1981.

5) J.N Bombay, A.C. Lange, D.W. Shimer, "A High-Power Switchmode DC Power Supply for Dynamic Loads", 1994 IEEE Industry Applications Society Annual Meeting Conference Record, Oct. 2-7, 1994.