ACCELERATOR MAGNET POWER SUPPLY USING STORAGE GENERATOR

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Abstract

Recently, a study investigated the feasibility of a large, 60 GeV accelerator. This paper presents the conceptual design of the magnet power supply (PS) and energy storage system. The main ring magnets will be supplied by six, high-voltage and two, low-voltage power supplies. These power supplies drive a trapezoidal shaped current wave through the magnets. The peak current is 10 kA and the repetition frequency is 3.3 Hz. During the acceleration period the current is increased from 1040 A to 10,000 A within 50 msec which requires a loop voltage of 120 kV and a peak power of 1250 MW. During the reset period, the PS operates as an inverter with a peak power of -1250 MW. The large energy fluctuation necessitates the use of a storage generator. Because of the relatively high operation frequency, this generator will operate in a transient mode which significantly increases the rotor current and losses. The storage generator will be directly driven by a variable speed drive, which draws a practically constant power of 17 MW from the ac supply network and eliminates the pulse loading. For the reduction of dc ripple, the power supplies will operate in a 24 pulse mode.

INTRODUCTION

The Advanced Hadron Facility consists of an oval shape main ring with 80 magnets connected in series. The magnets in the main ring loop have 0.068 H inductance and 0.106 ohm resistance, including the busbar inductances and resistances. The Main Ring General arrangement is shown in Fig. 1. The required magnet current is shown in Figure 2a. The calculated voltage and power needed to drive the current through the loop is shown in Figures 2b and c. This system operates with a 3.3 Hz frequency and the operation cycle is divided into four periods:

- o Injection: The power supplies keep the magnet current constant at 1040A which requires low voltage and power.
- o Acceleration: The power supplies increase the current rapidly from 1040 A to 10,000 A. This requires high voltage and power because the energy stored in the magnets increases from 0.37 MJ to 34 MJ.
- o Flat top: The power supplies keep the magnet current constant at 10,000 A, which requires relatively low voltage and power.
- o Reset: The power supplies produce large negative voltage to reduce the current and energy stored in the magnet from 10 kA or 34 MJ to 1040A or 0.37 MJ, respectively.

DESIGN CONSIDERATIONS

The magnet design studies indicate that the magnet's insulation to ground can be economically designed to withstand up to 10 kV peak voltage. This suggests that the power supplies should be distributed along the ring to keep the voltage to ground less than 10 kV.

These requirements resulted in the division of the loop into six sections as shown in Figure 1.

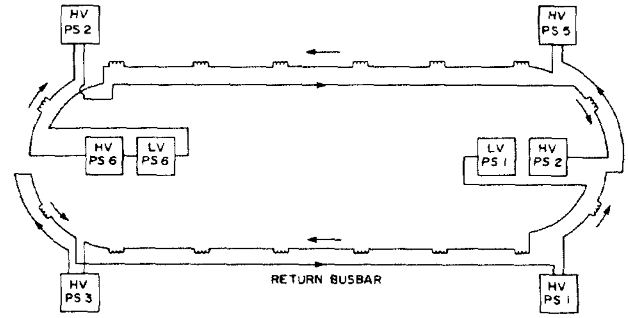

Fig. 1 Main Ring General Arrangement

Figure 2a shows that during the flat-top and injection period low voltage is needed to maintain the current. But, during the acceleration and reset period, high voltage is required to increase or decrease the current. This can be achieved by using six, high-voltage power supplies. These operate only during acceleration and reset period. They are bypassed during the injection and flat-top period, when two low voltage power supplies keep the required current constant.

During the acceleration period, the power supplies operate as rectifiers; but during reset, they operate as inverters which require full thyristor controlled bridges.

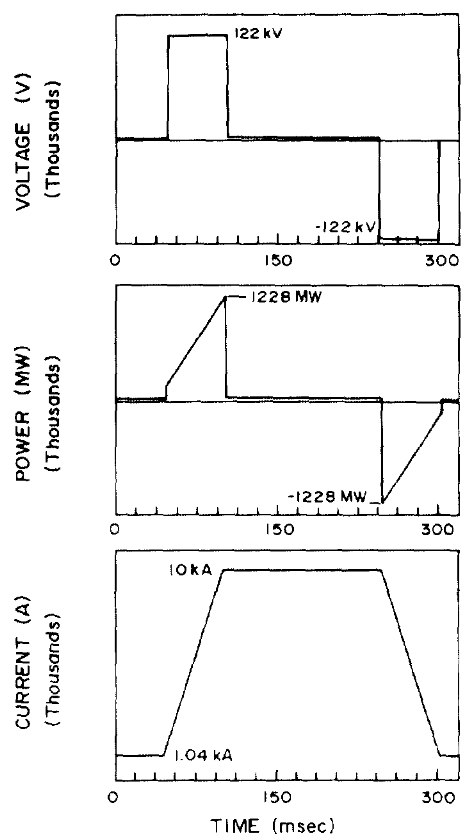

Fig. 2 Main Ring Voltage, Power and Current

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The dc current ripples disturb the beam. The permitted ripple current is less than 20 A. The system analyses shows that this can be achieved by using 24 pulse operation and capacitor filters. A further advantage is that this system can be controlled every 694 μs by adjusting the firing angle of the thyristors.

The power supplies drive variable current through the magnet loop. The magnetic field generated by the loop current may produce disturbances in electrical and electronic circuits located near the accelerator. In order to reduce or eliminate this magnetic field, the magnets will be interconnected in such a way that they form a dual loop as shown in Figure 1. In this arrangement the magnets will be connected so that the magnetic field at each magnet will be in the same direction but the external field disturbances will be minimized by providing a return current path.

During the acceleration period, the power supplies draw about 34 MJ to charge the magnets, which results in 1200 MW peak power. During the reset period, the power supplies remove 34 MJ energy from the magnets. This operation requires a large energy storage device because the local electric network is unable to supply this large pulse load. Capacitive, inductive and fly-wheel generator energy storage systems were compared.

The study indicated that at the present time the fly-wheel generator is the most economical storage device because several large surplus nuclear generators are available in the U.S.

SYSTEM DESCRIPTION

a) Power Supplies

The system will be supplied by six, high-voltage and two, low-voltage power supplies. Figure 3 and 4 show the one line diagram of a high- and low-voltage power supply. Both power supplies operate in 24 pulse mode and consist of two twelve pulse converters connected in series.

The twelve pulse converters in the high voltage power supply are built with two thyristor bridges connected in series. Each bridge is rated 5 kV, 4200A(avg). Each leg of the bridge contains a thyristor module with three liquid-cooled high voltage thyristors. The module is rated to 6 kV and 1400A (avg). The thyristors are equipped with snubber and firing circuits. Each bridge is shunted by a bypass which consists of three thyristor modules in parallel.

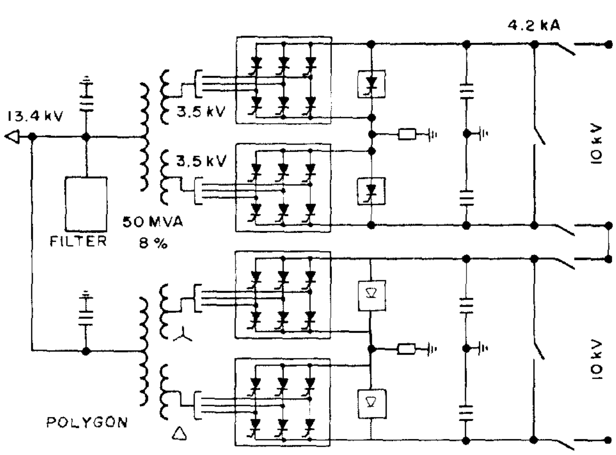

Fig. 3 HV Power Supply

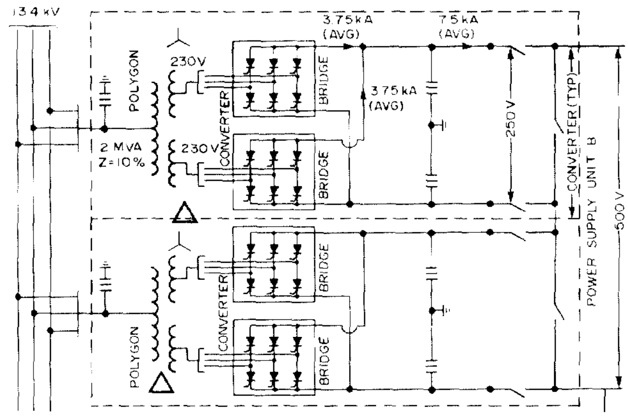

Fig. 4 LV Power Supply

The converter is protected by Metal Oxide (MOV) surge arresters and equipped with filter capacitor. The disconnect switches permit reduced power operation of the system during the maintenance or failure of a converter.

The twelve pulse converter in the low voltage power supply is built with two thyristor bridges connected in parallel. Each bridge is rated to 500 V 4200 A (avg). The bridge is built with six, high-power, liquid-cooled thyristors. It is protected by MOV surge arresters and equipped with disconnect switches.

Both the high and low voltage converters are supplied by a polygon/delta/wye connected transformer. The secondary voltages of these converter transformer will be shifted by -7.5° and 37.5° relative to the primary voltage if supplied by positive sequence voltage. If it is supplied by negative sequence voltage the phase shift will be -22.5° and +7.5°. The converters will be connected in series and thus operate in 24 pulse mode.

The 24 pulse converter mode will produce a smooth dc current. Only two (2) 150 kVAR capacitors are needed for filtering on the dc side of each converter. Each converter generates harmonics on the ac side. These harmonics produce disturbances in the primary ac power network and may cause overheating in the fly-wheel generator. The harmonics will be reduced by filters connected directly to each converter transformer's primary terminals. Each filter will consist of a tuned circuit (for the 11th & 13th harmonics) and a high pass unit for 23rd, 25th and higher order harmonics.

b) AC System

The one line diagram of the ac system is shown in Figure 5. The system consists of a fly-wheel generator with forced excitation. The fly-wheel generator will be a surplus nuclear generator rated about 1000-1200 MW. The generator rotor has to be reinforced to permit the startup by a variable speed drive device.

The generator will be driven by a variable speed drive system, which will consist of a load commutated rectifier-inverter system. This system rectifies the voltage of the 13.4 kV, 60 Hz and the inverter converts this dc voltage to variable frequency ac voltage. The variable frequency ac starts and drives the generator as a synchronous motor. The generator speed can be adjusted accurately and the system draws constant power from the 60 Hz ac system. The power will be kept constant by the gate control of the thyristors in the rectifier/inverter circuits.

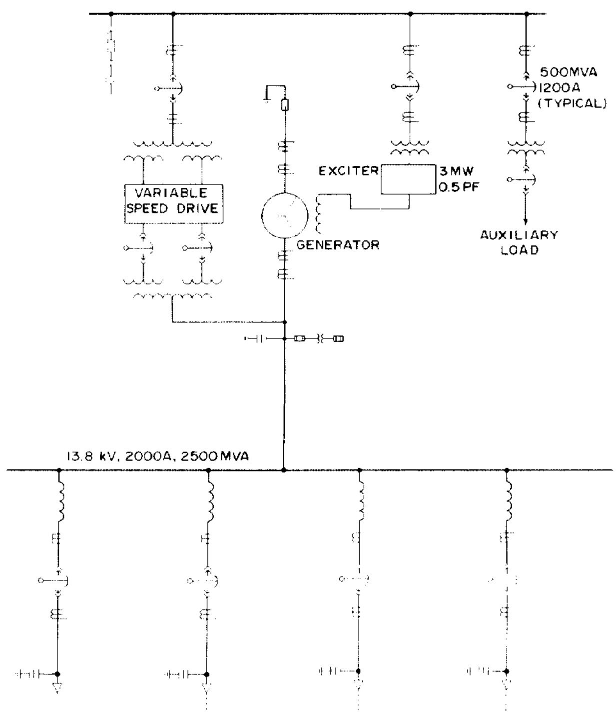

Fig. 5 Ac System with Flywheel Generator

During the acceleration period the generator together with the variable speed drive supplies the energy to all magnets through the converter systems.

During the flat top period the variable speed drive will provide energy for both the generator, which is accelerated as a motor, and for the two low voltage rectifiers supplying the magnets.

In the reset period, both the energy recovered from the magnets and the power supplied by the variable speed drive, accelerate the generator and increase the generator frequency nearly to the initial level.

During the short injection period, the variable frequency drive again supplies energy for both the magnet (through the two low voltage rectifiers) and for the generator (which is accelerated).

The constant power of this variable frequency drive will be selected in such a way that the original frequency is restored at the end of the injection period. It is estimated that the system draws more or less constant load of17 MW from the 13.4 kV 60 Hz busbar.

The one-line diagram on Fig. 5 shows that the generator and the inverter outputs will be connected to a 13.8 kV variable frequency busbar directly, i.e. without a generator circuit breaker. The magnet power supplies will be located at the six power supply buildings and they will be supplied via power cables from the variable frequency busbar. Current limiting reactors will be inserted in each power feeder to limit the short-circuit to 1000 MVA and will permit the use of standard metal enclosed switchgear.

OPERATION ANALYSES

A computer model has been developed for this study of the power supply operation. This model simulated the 24 pulse operation and confirmed that the dc current harmonics and ripples are less than the maximum permissible value, assuming proper firing. However, the firing inaccuracy may increase harmonic content and produce beam disturbance.

The study of generator operation revealed that the generator will operate in a transient mode because of the fast (50 ms) extraction of power. Transient operation increases the rotor current and induces undesirable rotor heating. This heating effect has been studied by Brown Boverco. The study confirmed the predicted rotor current increase but showed that the 1000 MW generator will be able to operate in this mode without any danger.

COST ESTIMATE

The cost estimate of the designed system assumed that the power supplies will use standard U.S. manufactured thyristor modules. The converter transformers are similar to the transformers used at the Princeton TFTR Tokomak Fusion Reactor. The actual purchase price of the transformers were escalated. The generator was assumed to be available free of charge, therefore only the transportation, fundation and auxiliary equipment costs are included. The operation cost estimated by using the calculated system losses and the DOE recommended present value (20 years operation time) multiplier. The total estimated cost of the electric systems is $145-155M. The estimated hardware and installation cost is $95-100M. The present value of the operation maintance cost is $50-55M.

CONCLUSIONS

The electrical power system is designed for the Advanced Hadron facility acceleration. It has the following major attributes:

- o The system can be built with proven, tested components
- o The system operation is verified by computer analyses
- o The system draws constant power from the ac network
- o The design is cost effective
- o The hardware and operation cost ratio is approximately two

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