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NEUTRAL BEAM POWER SUPPLY

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A SCR SWITCHED CAPACITOR VOLTAGE REGULATOR FOR 150 kV NEUTRAL BEAM POWER SUPPLY

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This paper describes the LBL, MFE Neutral Beam Test Stand III B high voltage regulator system. The regulator is 100% solid state and provides 1% regulation at power levels in excess of 10 MW for 50 msec. Regulation is achieved by switching charged capacitors in series with a large main capacitor bank which supplies the bulk of the power.

1.0 Introduction

The LBL Neutral Beam Test Stand III B high voltage power supply is a 1.56 MJ 150 kV regulated capacitor bank. The capacitor bank consists of 3 300 μ F 54 kV electrolytic capacitor banks and a 68 section .26 MJ regulator bank. It was decided to use a Marx type regulator rather than a more traditional series regulator to maximize the use of the stored energy. If a series regulator was used, the capacitor bank would have to be overcharged to allow for the voltage drop across the series regulation device. The Marx regulator does not require overcharging, thus reduces the problems of corona prevention and reduces the voltage rating of some of the power supply components. Rather than dissipating stored energy in a series regulator tube, capacitors are switched in series with the main capacitor bank to boost the output voltage as the main capacitor bank voltage drops. This approach lends itself to a 100% solid state high voltage regulator. The block diagram of the power supply is shown in Figure 1.

2.0 Circuit Description

Figure 2 shows a simplified circuit diagram of the high voltage regulator. Before any sections of the regulator are turned on, the current flows through diodes D_1 , D_3 , . . . and D_{135} . After the power supply output voltage has dropped below the desired voltage, SCR switch S_1 is fired. This reverse biases D_1 , and forces the current through C_1 , increasing the output voltage by the voltage C_1 is charged to. Again after the output voltage has dropped below the desired level, the next SCR, S_2 , is fired and the voltage increases again. This

process continues until all 68 of the SCR's have been fired, at which time regulation is lost. The regulator capacitors are charged by grounding the cathode of the SCR S_{68} and charging from the anode of SCR S_1 . All of the capacitors are charged through the diodes. A SOLA transformer is used in the charging supply to limit the charge current.

3.0 Noise Suppression

Various methods to suppress switching and noise transients are employed in the voltage regulator. Each capacitor section has a di/dt limiting inductor to limit the current rate of rise through the SCR's. Each SCR switch and diode has a voltage limiting metal oxide varistor across it to prevent over voltage transients from triggering or damaging the components. A series RC network is connected to the output of the regulator to suppress transients from coming back from the main capacitor bank and triggering the regulator SCR switches. Figure 3 shows the detailed schematic diagram of one regulation section.

4.0 Optimum Regulation Section Capacitance

An optimum value of regulator section capacitance exists to maximize the total pulse length, given the number of sections, total power supply stored energy available, and regulator module voltage. The total pulse length is given by

$$t_{\text{pulse}} = \frac{\Delta E C}{I} \sum_{m=0}^n \frac{C_1}{C_1 + mC} \quad (1)$$

where ΔE = voltage of each regulator section, C = capacitance of main bank, I = output current (assumed constant), C_1 = capacitance of regulator section, and n = total number of regulator sections. The total stored energy is given by

$$J = \frac{1}{2} CE^2 + \frac{n}{2} C \Delta E^2 \quad (2)$$

where E = voltage of main capacitor bank. The pulse length for a given amount of stored energy and main bank capacitance is

$$t_{\text{pulse}} = \frac{\Delta E C}{J} \sum_{m=0}^n \frac{2J - CE^2}{2J - CE^2 + mn C \Delta E^2} \quad (3)$$

To stay within the specified regulation requirement of $\pm 1\%$ of 120 kV. The regulator section must each be charged to less than 2,400V. The section voltage must be proportionally lower at lower power supply output voltages. Existing electrolytic capacitor banks designed by Lawrence Livermore Laboratory are used for the regulator bank because they can conveniently be divided up into 68, 800V sections. This voltage can be held off with existing SCR's and diodes without having to connect them in series. For a given number of capacitors available to use in the power supply, the capacitors can

be divided up between the main bank and the regulator banks to give the optional configuration for maximum pulse length. Figure 4 shows a graph of the total pulse length vs the capacitance of the main bank, given that the total stored energy is 1.56 MJ (9,792 2,000 μ F capacitors charged to 400V), output voltage = 160kV, and regulator bank voltage = 800V. The optimum capacitance of the main bank is 100 μ F. This configuration will give a total pulse length of 54 msec.

5.0 Trigger Transformers

Each regulator section requires a separate SCR trigger transformer. These transformers are constructed with a 4 turn primary and a 2 turn secondary on a Ferroxcube 144T500 ferrite core. Voltage isolation is achieved by winding the transformers with 30 kV high voltage wire. All of the cores are supported horizontally by one of two acrylic rods extended vertically through the middle of the cores. All of the transformer primary leads are twisted pairs and are channeled through one of two 1.5" diameter copper pipes from the floor to a hole adjacent to each individual trigger transformer. This copper pipe provides good shielding for the trigger leads.

6.0 Trigger Chassis

The regulator bank trigger chassis fires the regulator section SCR's in a sequential order. Figure 5 shows a block diagram of the regulator trigger chassis. Initially, the shift register is reset so that all outputs (1 to 68) have 0 V on them. The data input of the shift register has a logical 1 voltage on its input. Whenever the clock is pulsed a "1" is shifted sequentially down the register. After 68 clock pulses, all of the shift register outputs will have logical 1 voltages on them. These outputs are gated with clock 2 so that the inputs of the pulse amplifiers have the proper shape pulse. After a section is triggered once, it will continue to be triggered every 100 μ sec until the neutral beam power supply output pulse is terminated.

A voltage comparator is used to detect when the neutral beam power supply voltage is too low. The output voltage is sampled through a 20,000:1 compensated voltage divider and compared with a reference voltage. Whenever the output voltage is too low, the comparator output voltage goes high and causes the regulator bank SCR trigger chassis to trigger an additional regulator section.

7.0 Diode and SCR Impulse Rating

The diodes and SCR's used in this regulator must be able to absorb much more energy than they are subjected to under normal operation. Should a transient from elsewhere in the power supply trigger one of the SCR's, say S₆₈, when the bank is being charged, the entire regulator bank will discharge through the SCR and the diodes. All of the components should be capable of withstanding this type of fault condition.

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TS III B ACCEL POWER SUPPLY

XBL 7710-10046

ACCEL VOLTS VS. TIME
G2 VOLTS VS. TIME
10 KV/MAJ DIV
 5×10^{-3} SEC/MAJ DIV

XBB 788 9384

REGULATOR OUTPUT VOLTS VS. TIME
2 KV/MAJ DIV.
5 M SEC/MAJ DIV.

FIGURE 1

TS III B ACCEL POWER SUPPLY BLOCK DIAGRAM

FIGURE 11

MILNES

FIGURE III

FIGURE IV

FIGURE V

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