Title

THE LAWRENCE BERKELEY LABORATORY POWER SUPPLY SYSTEM FOR NEUTRAL BEAM SOURCE DEVELOPMENT

Author

Owren, H.M.

Publication Date

1977-10-01

Presented at the Seventh Symposium on Engineering Problems of Fusion Research, Knoxville, Tennessee, October 25-28, 1977

Energy and Environment Division

The Lawrence Berkeley Laboratory Power Supply System For Neutral Beam Source Development

H.M. Owren, W.R. Baker, D.B. Hopkins and R.C. Acker

October 1977

Lawrence Berkeley Laboratory University of California/Berkeley

Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

LBL-6378

THE LAWRENCE BERKELEY LABORATORY POWER SUPPLY SYSTEM FOR NEUTRAL BEAM SOURCE DEVELOPMENT*

H. M. Owren, W. R. Baker, D. B. Hopkins and R. C. Acker

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

The Lawrence Berkeley Laboratory has developed and constructed a 20-kV, 20-A test facility for the development of multi-megawatt neutral atomic beam sources. This facility has been in service for approximately two years and routinely operated at 120-kV, 20-A, 0.5-sec pulses since April, 1977. The accelerator power supply system consists of four 50-kV, 20-A, 0.5-sec power modules which may be connected in a variety of series and parallel combinations. The primaries are controlled with ignitron contactors and induction voltage regulators. The high voltage output is shunt regulated with two DP-15-type triodes connected in parallel. A special varistor plate load is used to limit the anode voltage to 60 kV. High voltage switching is done with series connected silicon controlled rectifiers (SCR's). Solid state power supplies of 15 V dc at 2200 A, and 125 V at 2500 A are provided for the source filament and arc power.

Introduction

A typical neutral beam source and power supply system is shown in Fig. 1. The source consists of two major components, the ion plasma chamber and the ion accelerator structure. The operation is as follows.

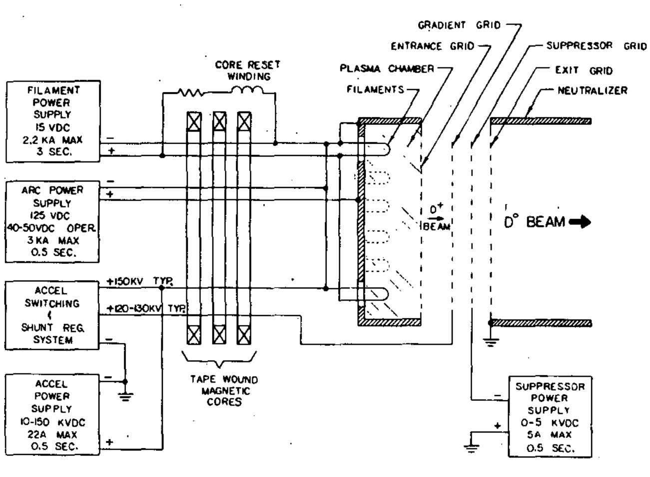

Figure 1. Block Diagram of Neutral Beam Source and Power Supply System.

Voltage is applied to the tungsten filaments. It takes ~ 2 sec for the filament to reach their operating temperature. A controlled flow of gas is then injected into the arc chamber. The arc power supply is then turned on and a plasma is established in the arc chamber. After the arc power has stabilized, voltage is applied to the accel electrodes and a beam of positive ions is directed down the neutralizer section of the beam line. This is a simple explanation of the operation. The essential characteristics of the various supplies is included in their description.

Filament Supply

The filament supply consists of a 60-cps, three-phase transformer with dual primaries and secondaries on each core leg. The primaries are connected in delta configuration and the secondaries are wound for a delta-wye connection. Each set of secondaries is connected to a three-phase silicon diode, full-wave bridge rectifier. These are connected in parallel through an interphase transformer to give 12-pulse operation.

The primary windings are connected to a three-phase induction voltage regulator. The voltage is adjusted manually with raise-lower push buttons or by the computer when in the computer operation mode. A magnetic contactor is used to turn on the primary power with protective circuits which limit the total on time for a given pulse to 3 sec.

The neutral beam source operates with the filament and arc chamber at maximum potential with respect to earth. This requires that the insulation between the secondaries and ground withstand the full accel potential. It is also desirable to minimize the capacitance to earth as the energy stored there will be available to flow into any faults that occur between the high potential end and lower potential electrodes. During conditioning of a source there are numerous faults of this kind.

The transformers are wound with the secondaries supported on standoff insulators. They are mounted in a gas-tight container which is pressurized to 1 + atmosphere of sulphur hexaflouride gas. Both the filament and arc supplies are in one large container. In later designs we have installed each in its own container.

ARC POWER SUPPLY

The arc power supply is designed to supply 2500 A at 60 V with an open circuit voltage of 125 V. The general construction of the rectifier transformer and diode rectifier assembly is the same as that of the filament supply. The primary voltage is adjusted with a three-phase induction regulator and is turned on and off with an ignitron electronic contactor. Adjustable line reactors are installed in each line to limit the maximum current available. The use of line reactors gives the required power supply impedance characteristics for stable arc operation. Stable arc operation is also possible using series resistors however substantial power will be dissipated in them.

* Work done under the auspices of the United States Department of Energy.

ACCEL POWER SUPPLY

Figure 2 is a block diagram and Fig. 3 a simplified schematic of the accel power supply. It has the following characteristics:

Output volts - Adj.	5 kV - 150 kV
Output voltage reg.	± 1%
Output current	20 A max. (for 0.5 sec every 60 sec)
Turn off time	3×10^{-6} sec
Recycle time after interrupt	5×10^{-6} sec

The power supply consists of four 50-kV, 20-A modules which may be connected in a variety of series-parallel combinations. The diagrams show the present test facility configuration with three supplies connected in series for 120-kV operation. Each power module contains a three-phase transformer with separate 25 kV delta-wye secondaries. Each of these secondaries is connected to a three-phase full-wave bridge rectifier. The two bridges are connected in series to give a 12-pulse, 50-kV output. The transformers and rectifiers are in a rectangular tank which is filled with transformer oil.

Line reactors are used to limit the short circuit current and the units are switched on the primary side with ignitron electronic contactors. One of the units has an induction regulator in the primary for coarse voltage adjustment.

When operating at low voltage, one or two of the supplies may be left off. The current flows through the bridge rectifiers of turned-off units. This provides for continuous voltage adjustment from a few kV to full output.

To limit in-rush current on the primary, the electronic contactors automatically phase-back for the first few cycles of turn on.

Accel Regulator and Switching System

Neutral beam sources will experience frequent "spark downs" during the conditioning process and even a fully conditioned source will have occasional ones. To protect the source and power supply from short circuit currents, some method of diverting current from the source and disconnecting the source from the power supply is necessary. In addition, the beam optics are affected by the voltages applied to the electrodes -- therefore these voltages are regulated. A fault indication can turn off this supply in a few microseconds. The accel voltage is regulated to ± 1%. It is also desirable to turn the supply on again as soon as the fault has cleared to keep the total on-time as long as possible.

Figure 3 is a simplified schematic of the shunt regulator and SCR switching circuit. The functions of the various components is as follows.

V1, V2, V3 and V4, with their associated networks, provide the shunt regulation. R1 provides the reference voltage. This unit consists of 600 metal-oxide varistors in series. A motor driven helical switch selects the desired number of MOV's for a desired accel voltage. V1 is an emission-limited diode to protect the varistors if the regulator goes out of range. Normally the voltage drop across V1 is too low to be a significant factor in the regulator operating level. The cathode follower, V2, (4CW10,000A) of the shunt regulator power amplifier drives the grids (V3 and V4, DP-15's connected in parallel). The load varistor R4 consists of a parallel-series combination of thyrite varistors. The non-linear voltage current characteristics of this material keeps the maximum voltage on the DP-15 anodes to less than 1/2 of the output voltage. This allows the use of existing tubes and is one of the advantages of the shunt regulator system. When the source load is disconnected the total power output of the accel power supplies flows in the shunt regulator. The plate load R4 is adjusted so that the voltage on the DP-15 anodes is between 5 kV and 15 kV. Most of the power is dissipated in the load R4 and not in the tubes V3 and V4. This load, R4, is oil-cooled with a heat exchanger to the cooling water system. When load current is delivered to the source load, the current in the regulator circuit is decreased by this amount. The voltage rises on the DP-15 anodes but, because of the approximately constant voltage characteristic of R4, the anode voltage does not exceed 1/2 of the output voltage. The minimum current in the shunt regulator circuit is ~ 10% of the output current to the source load.

Switching of the accel power to the neutral beam source is accomplished by the two SCR assemblies T1 and T2. The SCR's in T1 are turned on by applying a trigger to their gates at the appropriate time connecting the shunt regulated power bus to the first accelerator electrode. A fixed fraction of this voltage is applied to the second acceleration electrode by the resistor divider network R11 and R12.

To turn the voltage off, the SCR's in T2 are turned on. This shorts the power bus to earth. To insure that the current is diverted to this path additional diodes, D6, have been inserted in series with the bus to the neutral beam source. The capacitor in the L-C ringing circuit, L5-C5, will also be discharged and the impedance of this circuit is such that its current is approximately 3 times the load current plus the build up of fault current during the commutating cycle. The ring-around time is ~ 100 μsec. Normally, for 60 μsec the current is flowing from power supply to earth and for ~ 40 μsec, in the reverse direction through the diodes, D4, recharging the capacitors C3. All of the SCR's have now returned to their non-conducting state and the system is ready for another cycle. The number of cycles during a 0.5-sec pulse is determined by the setting of a variable time delay in the recycle trigger circuit.

Each SCR assembly, T1 and T2, is made up of six modules connected in series. Each module has 59 type C138N SCR's connected in series. A type V320LA40B MOV and a type 1N4723 diode is connected in parallel with each SCR. The MOV protects the SCR and diode from over-voltage and the diode provides a path for reverse current. All units were made identical so that only one type of spare is needed. The SCR's gates are each connected to a seperate secondary of a pulse transformer. Each pulse transformer has one additional secondary winding which is connected to the primary of next module.

A single-trigger pulse connected to the lowest module is cascaded to all of the primaries of the other modules. The modules are filled to one atmosphere with sulphur hex gas. The present units have been very reliable. We have had some failures of metal-oxide varistors due to too low a trigger current in the SCR gates. If an SCR does not trigger, the MOV will have to absorb ~ 4 kJ. This destroys the MOV but they fail in the shorted mode. With adequate gate signals we have not had any evidence of SCR "misfires". The design permits a number of shorted units in the stack without harming the overall performance.

Fault Detectors

A number of fault detectors are built into the system to protect both the neutral beam source and the power supplies. Source faults, which are considered normal to the operation, turn off the power applied to the source and after a preset time the power is reapplied to the neutral beam source. Other types of faults which may indicate an abnormal operation will terminate the pulse and will also require a manual restart.

The fault signals, which are generated by detectors sense; over-current to the # 3 accel electrode, an improper ratio of the voltages on the # 1 and # 2 electrodes, a negative dv/dt on the accel voltage indicating a short, a change during the pulse of the accel voltage, a high average current in the shunt SCR circuit (T2), and too many interrupts during a pulse. The primary circuits to the main power supplies are also protected with overcurrent relays and shunt trip breakers.

References

1. D. B. Hopkins, W. R. Baker and H. M. Owren, "A Shunt Regulator for 150-kV, 20-A, 0.5-Sec Neutral Beam-Source Power Supplies", Ninth Symposium on Fusion Technology, Garmisch, Germany, June 14-18, 1976.

2. W. R. Baker, D. B. Hopkins, B. H. Smith and W. L. Dexter, "Comparison of Series vs Shunt Regulation for Large Neutral Beam Source Power Supplies", 1976 IEEE International Conference on Plasma Science, Austin, Texas, May 14-16, 1976.

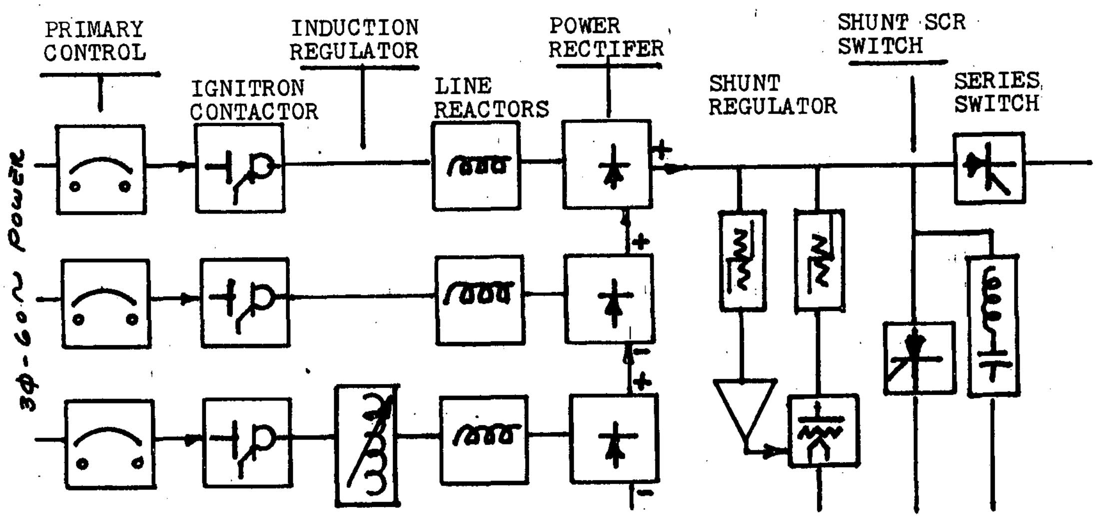

Figure 2. Block Diagram of Accel Power Supply System.

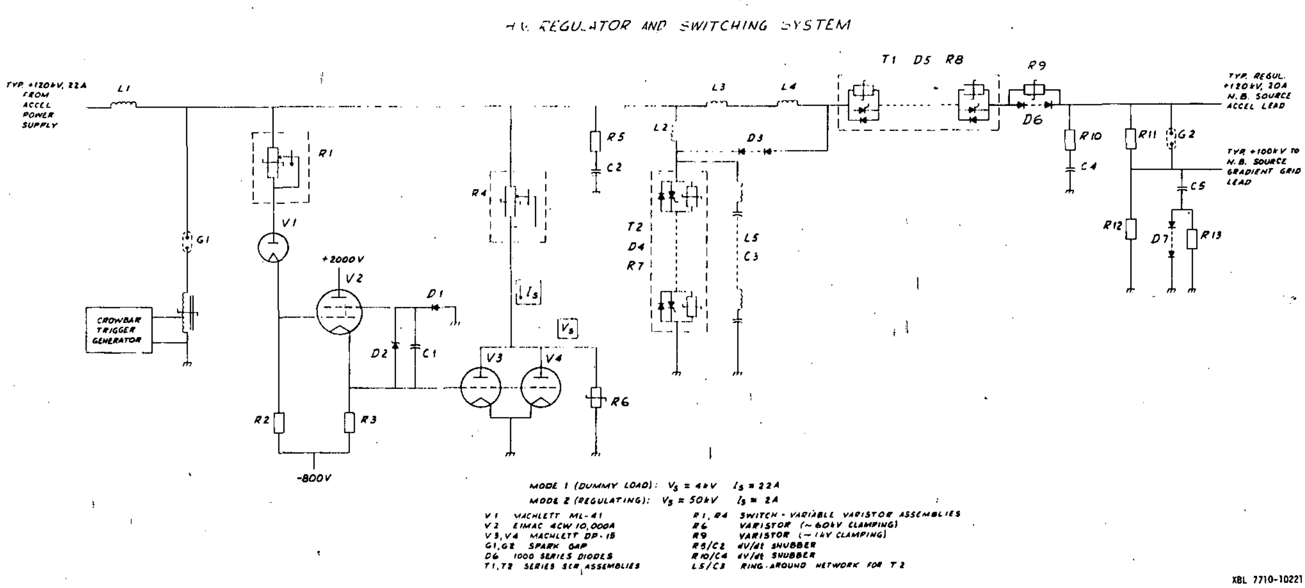

Figure 3. Simplified Schematic of Accel Shunt Regulator and SCR Switch System.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720