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Text of AIEE Conference paper on Bevatron Power Supply and presented at Pasco, Washington, August, 1957

BEVATRON POWER SUPPLY OPERATING AND MAINTENANCE PROBLEMS

by

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August 12, 1957

(1) The power supply for the Bevatron Magnet at the University of California consists of two flywheel motor generator sets delivering power to the magnet through ignitron rectifier-inverters. The magnet is pulsed 10 times per minute and the peak current is 8400 amperes at 14 kilovolts. (2) The rectifying period to peak current is approximately 2.0 seconds. After this time the firing angle of the ignitrons is shifted so that the ignitrons act as inverters, allowing the energy released by the decaying magnet flux to accelerate the motor generators. The shift from rectification to inversion is made in two steps to reduce the transient torque on the generator shafts. Approximately 80% of the energy is recovered, the losses being supplied by wound rotor driving motors. The inversion period is approximately 2.5 seconds.

Each motor generator set consists of a 3600 horse power 12 kv, 3 phase wound rotor induction motor, a 67 ton flywheel, and a 46,000 kva, 12 phase, 837 rpm, 3195 volt synchronous generator. The generator is connected to provide four 3-phase wyes with neutrals. Each wye supplies a 3 phase bank of ignitrons. Two wyes are connected in series to provide 8 kv d.c. at no load; the other two wyes are similarly connected. These two half-machine groups are paralleled through an interphase transformer to provide the required current carrying capacity. The generators and half-magnets are connected so as to minimize the voltage to ground and to distribute, uniformly, the capacity to ground.

The ignitrons are double grid tubes, Westinghouse Type IPJ7, rated 2083 amps peak and 3000 volts d.c., 75% load factor. Power is supplied from the generator bus to the peaking transformers, the ignitron charging circuits and the a.c. grids of the ignitrons through step down transformers. The ignitrons fire at zero delay during rectification and at from 120 to 150 degrees delay during inversion. The exact angle is adjusted in accordance with the load and synchronizing requirements.

The generator voltage wave shape leaves much to be desired as it has an abnormally high harmonic content. This wave shape is of little consequence on the peaking transformers and ignitor circuits, but is of supreme importance on the a.c., or outer, grids of the ignitrons. Notches appear in the voltage wave at the instant of commutation, frequently reducing the grid voltage enough to extinguish the a.c. grid current. If this happens, the anode current does not commutate

(1) = 1st slide, etc.

to the tube involved, and the result is an inversion arc through. This condition was severe enough to cause a marked reduction in operating time. The solution was to supply the grids with a voltage derived from six generator phases through a zig-zag transformer bank. The grid voltage wave now used has a greater number of notches, but none are severe enough to extinguish the a.c. grid current. There was an immediate reduction in the number of inversion arc-throughs when this circuit was put in service.

(3) The a.c. grids of the ignitrons pose several problems, only partially solved at present. The first is the positive grid signal which is derived from the output of three halfwave copper oxide rectifiers, correctly phased with respect to the ignitor pulse. This signal must be maintained during anode conduction and removed during anode blocking. The 150 degree phase shift required between rectification and inversion adds relays and complications. The inversion signal is the normal signal with relays to advance the grid voltage phase during rectification. As may be imagined, relay contact life is not of the best, and an occasional relay fails because of abnormal grid currents during fault conditions.

At the present time we are seriously investigating thyratron circuits triggered by the ignitor pulses to replace both the copper oxide rectifiers and the relays. Circuits proposed by the Radiation Laboratory staff and by the manufacturer are both being tested in daily operations. These circuits show excellent promise, and will use the same thyratrons as the ignitor firing circuits.

Fast voltage spikes and over-voltages during faults gave considerable trouble at first, repeatedly causing the coupling transformers between the a.c. and d.c. grids to fail. The cure was to bypass the a.c. winding with a capacitor. Similarly, grid over-voltages were controlled by a spark gap tube paralleling a capacitor.

The d.c. control grid is relatively trouble-free; the main source of trouble is the six phase d.c. bias supply. The selenium rectifiers occasionally fail, and the accompanying fireworks can be a source of danger. To date nothing serious has occurred.

The ignitron firing circuits have been another source of trouble. Each ignitron has its individual circuit to produce the ignitor pulse. A firing capacitor is charged to 1000 volts, using generator voltage rectified by a charging thyratron. Generator voltage is applied to peaking transformers to produce the sharp rectification and inversion trigger signals for the firing thyratron grids. Each thyratron discharges a 1000 volt capacitor through a reactor and coupling transformer to produce an ignitor pulse. A blocking rectifier prevents flow of current from the mercury to the ignitor. Originally, each ignitron had its own rectification and inversion peakers. Ignitor firing time jitter caused ignitron malfunction and it was therefore necessary to fire the two ignitrons in parallel on each phase from one set of peakers.

The original firing thyratrons were WL 677's, whose life and habits left much to be desired. They were temperature sensitive; above 55C they would fire at random. Mercury condensed on the elements and the tube would fire when shaken. They were expensive, and had a disgustingly short life of a few hundred hours. Also, the grid structure was supported mechanically at the top, less than an inch from the anode lead. Mercury deposits on the glass envelope made a fine voltage divider, allowing the grid to go positive!

(3) off.

Next we substituted GL 5545 thyratrons for the WL 677's. The former are argon filled, work excellently at 85C, are not sensitive mechanically and last over 4000 hours. A full supply was ordered. Then we found out that the GL 5545 had been superseded by the GL 6807 and were no longer available.

The GL 6807's work fine, except that under our operating conditions they are subject to gas cleanup which extinguishes the arc. We replaced 48 of them in one night. We still use then but keep an eye on their behavior. Also, we are service testing NL 760's, which are a mercury-argon tube. Although these have not been in service long enough to evaluate completely, we are hopeful.

For charging the firing capacitors we use either FG 104's or WL 677's. Both give satisfactory service.

Other components in the firing circuits are copper oxide rectifiers, relays, resistors, transformers, reactors and capacitors. There has been some relay trouble on the ignitor shorting system, caused by the cleaned-up 6807's. The tube arc extinguished and the firing capacitor discharged through the relay, destroying it. Reactor mounting bolts offered a flash-over path so they were replaced with bakelite rods. No transformers have failed yet. Rectifiers occasionally fail, but not often enough to be a nuisance. A rash of grid capacitor failures on the firing thyratrons was solved by replacing all with higher voltage capacitors. Bleeder resistors do fail, leaving charged firing capacitors lying in wait for unwary operators.

The ignitrons themselves present characteristic problems. Some tubes slowly degenerate, as shown by increasing arc-back and arc-through rates, and then suddenly fail to hold off anode voltage. Frequently these tubes are gassy and have pressures as high as five microns after an arc-back. Almost always the glass anode insulators become coated internally. This coating contains copper, which we believe comes from a brazed joint between the kovar seal and the anode stem. When the coating appears rapdily, failure is sure to follow. Several of the glass anode insulators were pitted internally, and glow discharge was observed during d.c. high potential tests. Attempts have been made to remove the coating with high potential d.c. discharges, but the results are not permanent.

Gassy tubes may be caused by internal contamination or by leaks. Flanged, threaded, and welded joints have all leaked. Periodic rate-of-rise tests and leak hunting, using a Consolidated Electrodynamics leak detector and helium, reveal system leaks. These may be remedied by tightening, new gaskets, or, as a last resort, varnish. The vacuum pumps must be kept in good order. Good pumps can keep a gassy, but otherwise satisfactory tube in service. Sluggish pumps allow the pressure to rise during pulsing and arc-backs result.

When a tube fails for any reason, it must be reconditioned. This means dismantling the tube, replacing the anode stem and seals, and reassembling. At this time, the grid bushings are welded to eliminate leaky threaded joints. All welds are leak-tested by pressurizing the tube with helium and inspecting each weld with a leak detector. Certain sharp edges on internal heat shields are rounded to reduce the voltage gradient and openings are made in the heat shield to increase pumping speed near the anode seal. The graphite parts are outgassed in a vacuum furnace at 1500°C.

The inside of the tank is blasted clean with aluminum oxide grit and blown clean with dry nitrogen. Clean tanks and degassed graphite parts are stored in vacuum if they must be left overnight.

After reassembly, the tube is pumped down and outgassed at low voltage. The degassing current is increased in steps as the residual pressure decreases. The steady state degassing schedule of 3 minutes at 600 amps and one minute at 1300 amps, per tube, is continuous, 24 hours per day.

When a tube is first put into service it is necessary to operate the tube at reduced rating. Operation starts at about 60% of rated voltage and at low current. Current, voltage, and pulse rate are gradually increased to normal values as outgassing progresses. The rectifier output voltage is monitored continuously with an oscilloscope and increases are made only when there are no voltage disturbances. At least eight hours of operation, and often more, are necessary to bring a new tube up to rated operation. Even with these precautions, the tube remains sensitive for several days.