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PLT NEUTRAL INJECTION IGNITRON
ACCELERATING SUPPLY

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ABSTRACT

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A phase-controlled rectifier has been designed for the accelerating supply on the PLT Neutral Beam Injection system at PPPL. The rectifier must furnish 70 amperes at up to 50 KV for 300 milliseconds, with a duty cycle of up to 10%. Protection of the injectors requires the supply to withstand repeated crowbarring. The rectifying element selected to satisfy these requirements was a commercially-available ignitron, installed in a supporting frame and using firing circuits and controls designed by PPPL.

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INTRODUCTION

The neutral particles injected into the PLT for plasma heating must first be accelerated as positive ions before they are neutralized and injected into the plasma. The accelerating supply must furnish a peak current of 70 amperes at 50 KV with a pulse duration of .3 second and a duty cycle of 10%. As the injectors are often operated at their voltage limit, there is a probability of internal faults between electrodes during the pulse. Since the injection pulse length on the PLT is .3 second, it is advantageous to crowbar the power supply to clear injection faults and rapidly turn the injector back on during the same .3 second pulse.

It was decided to use a phase-controlled rectifier for voltage control instead of some other method, such as a variable transformer. Since the supply will operate initially directly from the power line, the phase control enables it to be controlled and varied from 5 KV to 50 KV relatively rapidly. It provides about 1% regulation which reduces the required dissipation in the modulator tube in series with the injector load. A twelve-pulse rectifier was decided upon to provide low ripple and low cost filters. It consists of two three-phase full-wave bridges in series, one of which is connected to the wye-secondary, and the other connected to the delta-secondary of a 1.5 MVA rated transformer.

Ignitrons were chosen over silicon-controlled rectifiers as the phase-controlled rectifier elements for several reasons:

1. The peak-inverse-voltage across each leg of each bridge is 25 KV. With present day SCR's many units would have to be used in series in each leg. They would require distribution networks to compensate for differences in turn off, turn on, inverse leakage and gate characteristics between individual elements on each leg of each bridge; therefore, ignitrons are a more economical choice because only three standard type 5555 welding ignitrons are required in each leg.

2. As previously stated, the pulse duration is .3 second. Because of the relatively short thermal time constant of semi-conductors, an SCR must have current rating which is comparable to the maximum pulse current, while the ignitron average current rating can be closer to the value averaged over the entire interval between pulses.

3. Arc-backs and overloads do not result in permanent damage to ignitrons if the faults are removed in the time it takes a circuit breaker to open, whereas they can be catastrophic to SCR's (the ignitrons in this rectifier could withstand a bolted output short with the current limited by the reactance in the transformer and power line for an hour with no permanent damage).

These rectifiers have application to injector systems for larger CTR devices, such as the Tokamak Fusion Test Reactor which will require approximately 110 MW at 124 KV. They could be connected in series, and with the use of the proper power transformer could supply the 124 KV accelerating voltage for the neutral injection ion sources.

DESCRIPTION

A. Main Frame

Figure 1 is a photograph of the rectifier showing the ignitrons, firing boards, light emitting diode circuits, voltage dividing capacitors, and bypass ignitron diodes. The left half of the rectifier is a 25 KV, three-phase, full wave bridge connected to the wye secondary of the 1.5 MVA power transformer, and the right side is a second 25 KV, three-phase, full wave bridge connected to the delta secondary. Each leg of each bridge consists of three type 5555 ignitrons in series so that the peak-inverse-voltage across each is approximately 8300 volts. Additional ignitrons, connected as bypass diodes, can be seen to the right of each bridge. They allow the bridge halves to operate independently of each other and eliminate the need for quadruple pulsing, although double pulsing is provided for start-up and smooth control. The photograph also shows the one microfarad voltage dividing capacitors in series with 2 ohms across each ignitron to distribute the peak-inverse-voltage when they turn off after their conduction period. Anode current is returned through the four symmetrically placed aluminum rods to effectively form a type of coaxial construction. Light emitting diodes are in the boxes at the bottom of the rectifier and are coupled to their respective ignitron firing boards by trifurcated light pipes to simultaneously fire the three series tubes in each leg. The ignitrons are operated at 23 amperes average current compared to their maximum average current rating of over 200

amperes, so very little cooling is required to dissipate the heat generated in the tubes. The plumbing shown in the photograph is used mainly to keep the ignitron cathodes cooler than the anodes and the overall temperature cooler than the room ambient, in order to reduce the probability of arc-backs.

B. Ignitron Firing Circuit

Figure 2 is a simplified diagram of the ignitron firing circuit which is designed to produce two ignitron triggers 60° apart each cycle of the power frequency. Each ignitron has its own firing board that operates as follows: Capacitor C3 is charged through R4 and D9 during the time that inverse voltage appears on V2. The zeners, D3 and D6, clamp the voltage to -800 volts with respect to the cathode of V2. The triggers which are 60° apart are transmitted by one light pipe to the light activated SCR3. The LASCR discharges C2 through the pulse transformer T1. C2 is charged by C1, which is clamped to -10 V by D8, through R2. At the time the first pulse appears on the secondaries, T1A, T1B, of T1, SCR1 is forward biased and SCR2 is back biased by C3. Therefore, SCR1 discharges through L1, the ignitor, R6 and D10 as shown by the heavy line. The voltage C3 reverses and is blocked by D7 until the second trigger appears on the secondaries to T1 60° later.

At this time SCR2 is forward biased and SCR1 is back biased. Therefore, SCR2 fires through the path shown by the dotted line. Although losses in the circuit during the first pulse prevent C3 from reaching a full +800V, it reaches several hundred volts, depending on the condition of the individual ignitors. D9 is rated at 50 KV PIV to protect the firing boards

if only one ignitron out of three in each leg should fire for some reason. The zeners and SCR's are mounted on standard heat sinks.

C. Ignitron Triggers and Trigger Control

The trigger generation and distribution are quite conventional for a twelve-pulse rectifier of this type. Figure 3 is a block diagram of the rectifier which does not include overload or trigger blocking circuits which are described in Section D. Potential transformers on the three-phase input to the power transformer furnish signal voltages to the phase-distribution transformers which drive the phase delay circuits. The phase delay circuits are essentially ramp generators which start at the zero crossing of their respective AC input signal. These circuits also contain a comparator which compares its incoming ramp signal with an external signal from the phase control generator which is common to all delay circuits. In this way twelve independent pulses 30° apart are produced during each cycle of the power frequency; therefore, all triggers are delayed with respect to their AC input by the same amount which is dependent upon the control voltage from the phase control generator. The output triggers from two of the phase delay circuits are coupled to each light emitting diode circuit. These triggers are 60° apart, and each trigger fires a low power SCR. The two SCR's in each LED circuit discharge into a common LED. This LED then fires twice each cycle of the power frequency and drives the trifurcated light pipe which transmits the triggers to the ignitron firing circuits.

The phase control voltage generator consists of a standard error amplifier that compares the DC voltage at the filter output, or DC current from a current transducer, with a manually variable reference voltage that serves as the output level control. The response time of the regulator is determined by the time constant of the filter which is necessarily large (5 microfarads, .2 henry) to provide adequate filtering when the ignitrons are partially phased back.

D. Output Control, Interlocks, and Protection Circuits

The high voltage circuit breaker that supplies AC power to the rectifiers is interlocked with conventional relays. In addition there is a fast "trigger on-off" circuit which operates as follows: an external +200 volt signal can be interrupted at any time during the pulse by the injector fault detector (which also triggers a crowbar across the injector), as well as by any other external signal that might be generated when it is desired to turn off the rectifier by suppressing its triggers.

The +15 volt bus that supplies the collector voltage to the phase delay circuits can be shunted out by SCR's which are triggered by internal rectifier faults such as overvoltage, overcurrent, ignitron arc-pack, and line voltage transients. These faults also suppress the rectifier firing pulses, thereby turning the rectifier output off, although the high voltage AC is still on. These faults also trigger SCR's that pull in relays which, until reset, indicate the particular fault, and in some cases open the high voltage circuit breaker. The overvoltage and overcurrent circuits have individual set point controls and meters. In addition, there are separate circuits which limit

the voltage and/or current to adjustable set points but do not turn off the triggers or high voltage. They also give an external indication that the limit has been reached. The arc-back detectors consist of pulse transformer cores in each leg of the two bridges which are biased by a common power supply. The bias current can be removed or reversed for reading current in the forward direction as an aid in troubleshooting. The line-current transient detector consists of two low power rectifiers supplied by metering current transformers in the secondaries of the power transformer; one has the minimum amount of filtering necessary to filter commutating spikes, while the other one has a much longer time constant. The outputs of the two rectifiers are compared so that if a transient occurs, for example a missing AC current pulse or sudden short, the unbalance in the two rectifiers will generate a signal to fire the proper trigger-blocking SCR. Conventional relays are used for other interlocking and control functions.

TESTING PROGRAM

A. Construction and Testing at Manufacturer's Plant

Four identical rectifiers of this type are required for the neutral injection system used on the PLT. They are presently under construction. The constructor will be required to conduct some low power tests in conjunction with PPPL personnel prior to shipment. These tests are intended to demonstrate the quality of workmanship and materials, and to verify the adequacy of

design. The tests include a hipot of 60 KV terminal-to-terminal, and 100 KV from each terminal to the frame. Each bridge will then be tested by jumpering out two of the three series ignitrons in each leg and exciting the resultant bridge with a 480V/4160V, 150 KVA transformer; this will produce 5600 VDC at 26 amps steady-state. This configuration produces peak-inverse-voltages on the single ignitron approximately those of the actual system: the steady-state operation allows tests of closed loop regulator stability and response time, and equilibrium temperature of various components to be determined.

B. Testing at PPPL

The full-power portion of the test program will be performed at PPPL following installation of the complete AC system, high-power dummy load, crowbar, and required supporting equipment. This effort is scheduled to begin about January 15, 1976.

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Fig. 1

SIMPLIFIED IGNITRON DOUBLE PULSE FIRING CIRCUIT

Fig. 2.

Fig. 3.