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A SOLID STATE DC POLARITY REVERSING SWITCH*

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In applications where it is necessary to rapidly reverse the polarity of a dc magnet power supply, a mechanical reversing switch is used rather than reversing links or cables. If in addition to rapid reversing the application calls for frequent reversals, then the wear and tear of a mechanical switch will limit its life expectancy, and the advantages of an electronic polarity reversing switch become more attractive, in spite of the higher initial cost.

A typical reversing switch is shown in Fig. 1a. In each polarity only opposite arms of the bridge conduct at any time: A and B for one direction, A' and B' for the other. In an electronic reversing switch (Fig. 1b) the mechanical contacts in the arms of the bridge are replaced by thyristors or transistors with somewhat different properties depending on which device is used. Transistors require a continuous signal at the base for the "closed" condition, are easy to "turn off", but can handle only limited voltage and current. On the other hand, thyristors stay "closed" after they have been triggered, can only be "turned off" by reducing their current below some minimum holding value, and can handle relatively large voltage and current.

Two problems seem most important in the design and operation of a thyristor reversing switch. One is to assure complete turnoff of the conducting pair of thyristors before or at the time the opposite pair is turned on. The other problem results from the energy stored in a typical magnet load. A reversing switch could be built, in principle at least, using inverter circuit techniques as shown in Fig. 2. In this circuit, while SCR1 and SCR2 are still conducting, SCR1' and SCR2' are triggered to initiate reversal, with capacitor C providing the current that turns off SCR1 and SCR2. Some of the energy stored in the inductance L and in the load inductance L_R goes to charge up the capacitor in the opposite polarity. There are some complications with this approach, as additional inductance L_s is generally designed to limit the rate of rise of the current during commutation. Also, because the energy stored in the inductance L_R is typically quite large, the bipolar capacitor C also has to be large since it is necessary to limit the transient voltages on the magnet and on the thyristors. The circuit might become practical if switching action is restricted to low currents.

Of course, a reversing switch can be completely eliminated if a bipolar power supply is used, as shown in Fig. 3. The polarity of the output voltage depends on which set of thyristors is triggered in the antiparallel configuration. Current can be reduced to zero rapidly by inverter action. A drawback of this circuit is the high ripple at low current levels, since neither freewheeling diodes nor electrolytic filter capacitors can be used. In industry this scheme is sometimes used for motor reversing drives.

Properties of this Reversing Switch

A reversing switch is required for changing the polarity of the magnets in the beam transport system for the SLAC storage ring. The switch has to be able to carry 750 amperes at 200 volts continuously, and must be operated every ten minutes without opening the power supply circuit breaker. The intent is to add the switch to an existing thyristor controlled power supply that has an LC filter in the output.

The approach taken in the design of this reversing switch differs from the circuits discussed before. The circuit used is shown in Fig. 4, and has the following operating features:

a) Continuous gate pulses are provided to the appropriate thyristors for each direction of the load current. This is necessary since, as will be indicated later, no load current exists at the time the actual reversal is accomplished. Also, the application may require that the current be reduced to zero without reversing or extinguishing the conducting thyristors.

b) If a reverse command has been given, the circuit waits until the load current is reduced below the preset level, at which time the gate pulses to the previously conducting thyristors are interrupted. A current pulse that will oppose the existing power supply current is then applied through a transformer, thus assuring complete turnoff of the conducting thyristors.

c) The reverse command circuit is reset at the same time that the current turnoff pulse is applied, and after a small time delay gate pulses are applied to the other thyristor pair for the new direction of the load current.

Description of the Circuit

Thyristors SCR1 and 2, SCR1' and 2' of Fig. 4 are the contacts of the reversing switch. The thyristors chosen are rated for 1000A dc continuous current and 400 V peak reverse and forward voltage. Gate signals in the form of a continuous pulse train to either SCR1 and 2 or SCR1' and 2' are generated by a pair of blocking oscillators (Q6 and Q8, or Q5 and Q7), and are applied to the gates through pulse transformers (T4 or T5).

A transductor (DCT) in the load lines monitors the magnet current. The resistance in the transductor output is large since the circuit must be active only at load currents up to about 30A. The output of the transductor is clamped to 5 V dc, and is summed at the input of A1 with an external 5 V dc signal supplied through the polarity reversal command switch S and a small thyristor SCR3.

When a polarity reversal is desirec, the external 5 V dc signal is removed by a momentary interruption of the switch S, which turns off SCR3. As the load current and consequently also the transductor output signal is reduced to a level predetermined by the setting of the 100 ohm potentiometer, the change is sensed by a level detector circuit formed by A1 and A2. The output of the circuit immediately cuts off the operating blocking oscillator, thus interrupting gate pulses to the conducting thyristors in the bridge.

One second after the level detector has switched, a timing circuit formed by Q9 and Q10 generates a pulse, which after amplification by Q11 triggers SCR4, thus dumping the stored energy of the capacitor through T1 into the reversing switch power lines. The direction of the current pulse is such that it temporarily opposes any current that still exists in the thyristors and causes them to turn off. At the same time the small thyristor SCR3 is also triggered, applying 5 V dc to the level detector circuit and resetting it.

Two seconds after the level detector has switched, a timing circuit formed by Q1 and Q2 triggers a flip-flop (Q3 and Q4). The other blocking oscillator is then turned on, and the reversing cycle is completed.

The size of transformer T1 was determined empirically. A core of about 5 in^2 was sufficient, wound with a single turn from the switch power lines, and five turns from the dump

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capacitor source. The transformer has a gap of about 10 mils to prevent saturation at low dc currents where it must be active. For successful turnoff of the thyristors a few microfarads C' may be necessary across the load terminals. The duration of the two timing circuits was arbitrary and could possibly be shortened.

The four switching thyristors have RC networks connected across them, not shown in Fig. 4. They were added to prevent spurious triggering that could be caused if the allowable rate of rise of anode voltage were exceeded; the networks also aid in thyristor turnon during startup. The values of R and C depend on the thyristor chosen; about 10 ohms and 2 microfarads were adequate for this application.

The circuit can be simplified if the turnoff pulse supplied through T1 is not required. Since the holding current of thyristors may be as low as a few milliamperes, the turnoff pulse circuit can only be eliminated if the power supply current can in truth be reduced to zero, and if the time required for the current decay is not excessive.

Although other control schemes could be devised, for this application the choice of a continuous trigger and of the reset thyristor SCR3 was deliberate. It allows presetting and maintaining the polarity of the switch even if the current is reduced to zero, and permits reversing only at no load current when switch S is actuated. Continuous indication of switch polarity can be obtained by monitoring the blocking oscillators.

With currently available thyristors rated at about 1500 A dc, a somewhat larger switch than described here could be built. For still higher currents, it would be necessary to parallel thyristors for dc operation. This can be done, but requires the use of matched thyristors and of appropriate derating factors.

Tests and Results

The circuit was built and tested with a small magnet which was turned off and reversed when operating at about 20 A. It was also successfully tested with a 0.4 henry 5 A choke used as the load. Field operational data has not yet been obtained, but the switch is being installed for use with a power supply.

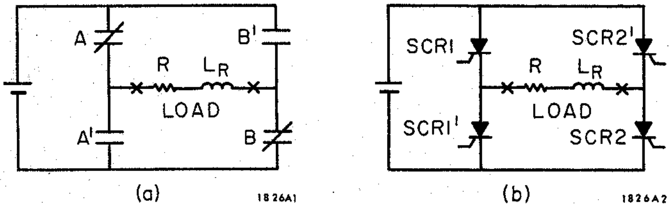


FIG. 1--a) Mechanical reversing switch.
b) Electronic reversing switch.

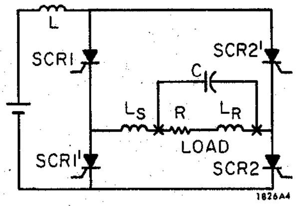


FIG. 2--Basic current-fed inverter circuit used as a reversing switch.

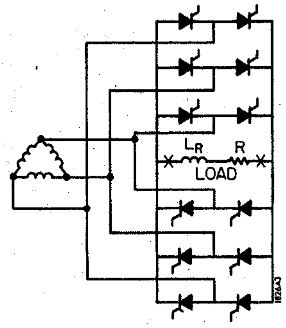
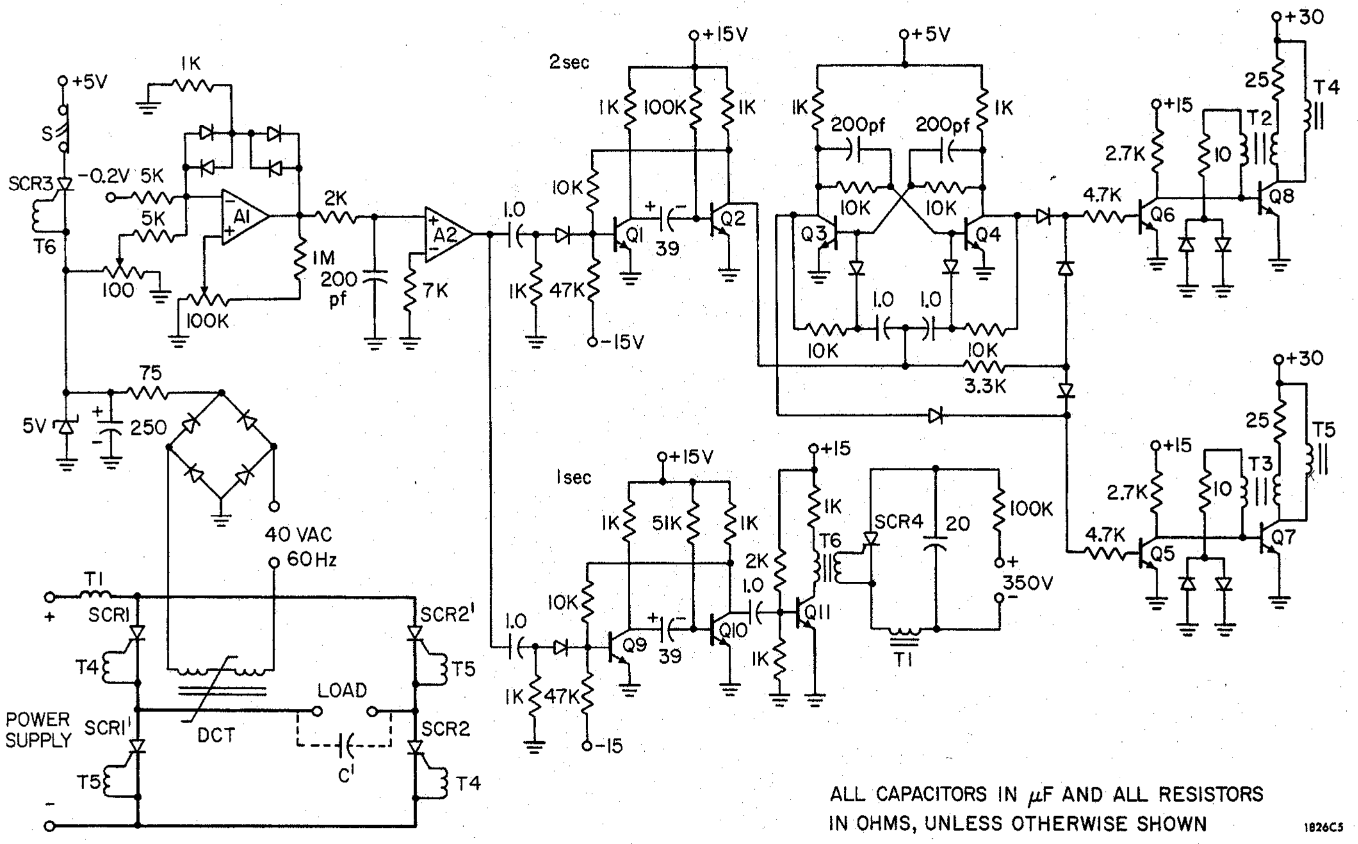


FIG. 3--A bipolar power supply using back to back thyristors.



ALL CAPACITORS IN μF AND ALL RESISTORS IN OHMS, UNLESS OTHERWISE SHOWN

FIG. 4--Schematic diagram of thyristor reversing switch.