Engineering Bulletin

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Power Products Application

SCR IMPROVES DC MOTOR CONTROLLER EFFICIENCY

SCRs are commonly associated with ac applications because of their drive simplicity and inherent self turn-off when the anode current drops below the holding current. However, with proper commutating techniques, they can be as readily used in dc applications. There are several ways of commutating the SCRs off in these circuits:

1. Using a series switch to open the anode circuit,
2. Using a switchable commutating capacitor which reverse biases the SCR anode-cathode, or
3. Using a clamp or shunt switch across the anode-cathode, thus diverting the anode (load) current.

For the clamp circuit case, the clamp must have a lower voltage drop than the SCR On Voltage V_{TM} and must be of lower impedance to ensure adequate current diversion.

Bipolar transistors make good clamp devices since saturation voltages $V_{CE(sat)}$ are well below that of the SCR V_{TM} (V_{TM} of an SCR is the sum of $V_{CE(sat)}$ and $V_{BE(sat)}$ of the two transistor equivalent circuit). For an NPN clamp transistor, the emitter can either be tied directly to the SCR cathode or to a negative voltage of about −5 to −10 V. The clamping action can often be improved for the negative voltage case.

Due to the extremely efficient utilization of silicon, SCRs can switch more current than a comparably sized transistor. And, the peak surge current ratings (1/2 cycle sine wave) can be perhaps ten times the RMS forward current $I_{T(RMS)}$ rating. In fact, the MCR71, an SCR specifically characterized for crowbar applications, with an $I_{T(RMS)}$ of 55 A, has a 2000 A peak, exponentially falling to 10% in 0.5 ms, surge current rating.

Admittedly, turn-on times of SCRs are not extremely fast, being in the 1/3 to 1.0 μs range, and can't compete in this regard with power MOSFETs, but they can handle much more surge current than other semiconductor technologies. These fast turn-on requirements become academic, however, if care in reducing wiring inductances is not taken.

How does one take advantage of the high surge current capabilities of the SCR in a dc circuit? A good example is in the pulse width modulated, dc motor controller developed by Ben White and Dale Lillard.[1] The motor drive portion of this golf cart controller is shown in Figure 1. Germanium power transistors were used by the authors because of the low saturation voltages and resulting low static power loss. However, since switching speeds are slow and leakage currents are high, additional circuit techniques are required to ensure reliable operation:

1. The faster turn-on time of the SCR (Q9) over that of the germanium transistors shapes the turn-on load line.

2. The parallelled output transistors (Q3–Q8) require a 6 V reverse bias.

3. The driver transistor Q2 obtains reverse bias by means of diode D4.

To obtain the 6 V bias, the 36 V string of 6 V batteries are tapped, as shown in the schematic. Thus, the motor is powered from 30 V and the collector supply for Q2 is 24 V, minimizing the dissipation in collector load resistor R1.

Total switching loss in switchmode applications is the result of the static (on-state) loss, dynamic (switching) loss and leakage current (off-state) loss. The low saturation voltage of germanium transistors produces low static loss. However, switching speeds of the germanium transistors are low and leakage currents are high. Loss due to leakage current can be reduced with off bias, and load line shaping can minimize switching loss. The turn-off switching loss was reduced with a standard snubber network (D5, C1, R2) see Figure 1.

Turn-on loss was uniquely and substantially reduced by using a parallel connected SCR (across the germanium transistors) the MCR265-4 (55 A rms, 550 A surge). This faster switching device diverts the initial turn-on motor load current from the germanium output transistors, reducing both system turn-on loss and transistor SOA stress.

The main point of interest for this Engineering Bulletin is the power switching portion of the PWM motor controller. Most of the readily available PWM ICs can be used (MC3420, MC34060, TL494, SG1525A, UA78540, etc.), as they can source at least a 10 mA, +15 V pulse for driving the following power MOSFET.

Due to the extremely high input impedance of the power MOSFET, the PWM output can be directly connected to the FET gate, requiring no active interface circuitry. The positive going output of the PWM is power gained and inverted by the TMOS FET Q1 to supply the negative going base drive to PNP transistor Q2. Diode D1 provides off-bias to this paraphase amplifier, the negative going pulse from the emitter furnishing base drive to the six parallel connected output transistors and the positive going collector output pulse supplying the SCR gate trigger coupled through transformer T1.

Since the faster turn-on SCR is triggered on first, it will carry the high, initial turn-on motor current. Then the slower turn-on germanium transistors will conduct, clamping off the SCR, and carry the full motor current. For the illustrated 2HP motor and semiconductors, a peak exponentially rising and falling SCR current pulse of 120 A lasting for about 60 μs was measured. This current is well within the rating of the SCR. Thus, the high turn-on stresses are removed from the transistors, providing a much more reliable and efficient motor controller while using only a few additional components.

Reference:

1. White, Benjamin and Lillard, R. Dale; "Pulse Width Modulation DC Motor Control"; Powerconversion International, January, 1984.

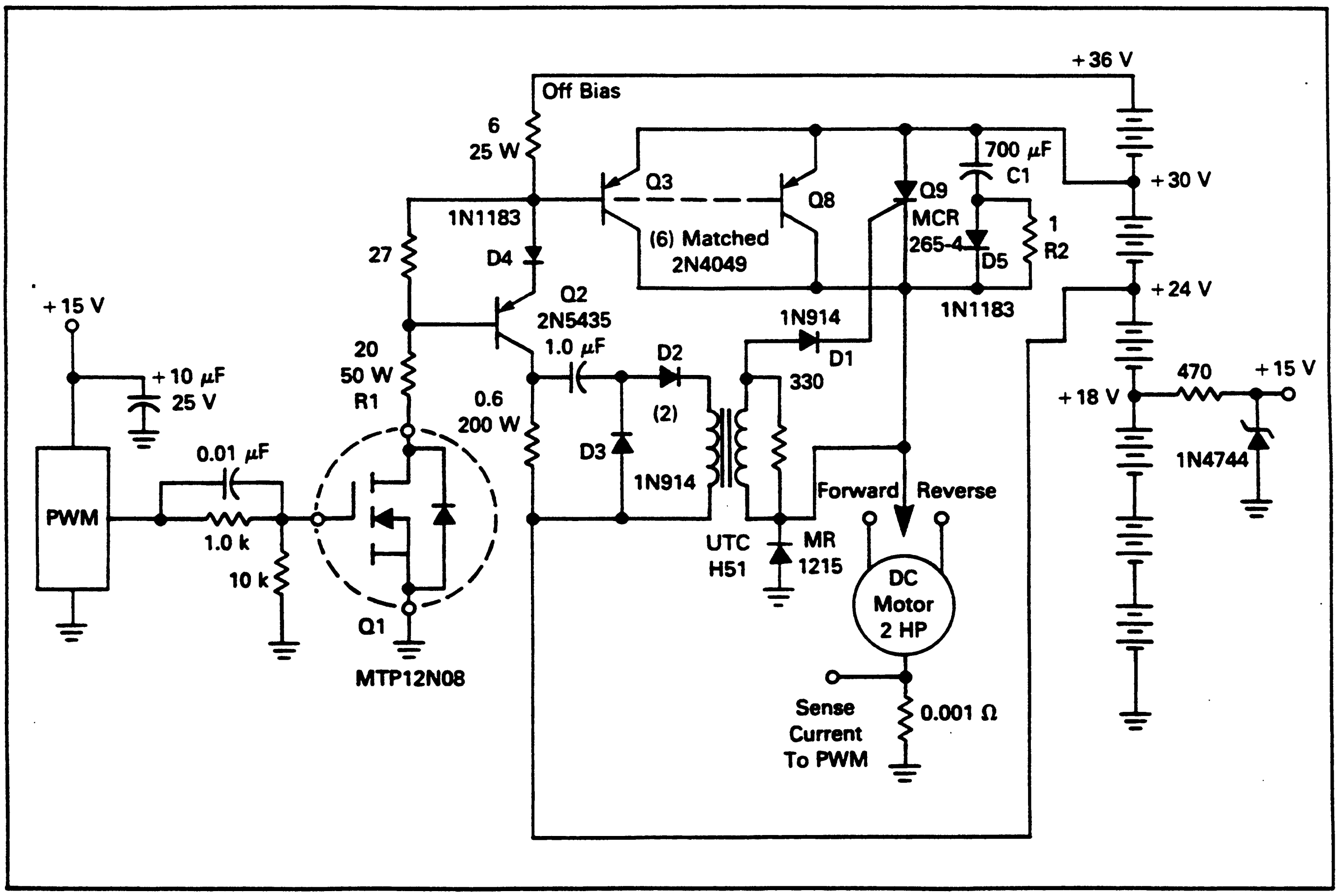

FIGURE 1 — PWM DC MOTOR CONTROLLER USING SCR TURN-ON FEATURE

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