Experiment # 9

LIGHT DIMMERS AND MOTOR SPEED CONTROL

INTRODUCTION:

As their name implies, SCR devices can often be used as controlled rectifiers. For example, the SCR is widely used in a light-dimmer control or for the speed control of simple series motors (such as electric saws and drills). A simple control of this type is shown in Fig. 1. To visualize the effect of this circuit, an analysis of the RC circuit must be considered. If the current of the gate of the SCR is assumed to be quite small, the current through the capacitor is

$$I_c = \frac{V_i}{R_1 + R_2 + 1/jwC} \qquad 1$$

where V_i is the input voltage. The voltage across the capacitor is

$$V_c = \frac{V_i}{1 + jwC(R_1 + R_2)} \qquad 2$$

Note that if $wC(R_1 + R_2) << 1$ then V_c is essentially equal to V_i. In contrast, if $wC(R_1 + R_2) << 1$ then V_c becomes approximately equal to $V_i / jwC(R_1 + R_2)$. This later value of V_c will lag V_i by approximately 90^o and will have a magnitude much less than V_i. Thus, for a given value of ωC, the magnitude and the phase angle of the gate voltage V_c in this analysis can both be adjusted by changing R_1+R_2 (or really just R1) in Fig. 1.

By adjusting the magnitude and the phase angle of the gate voltage, the time when the SCR fires can be controlled. This effect is illustrated in Fig. 2. In Fig. 2(a), the value of $wC(R_1 + R_2) << 1$, so the gate voltage has almost the same magnitude and the same phase as the applied voltage. Since the gate potential exceeds the firing potential very early in the cycle, current flows as if the SCR were a conventional diode. Near the end of the positive half cycle, the anode voltage is reduced to a value less than the hold-voltage of the SCR. The SCR becomes off and the load current drops to zero. However, since the hold voltage is usually much smaller than the amplitude of the input voltage, one can, approximately, assume that the SCR current will drop to zero when the anode voltage drops to zero. During the negative half cycle the voltages then reverse on the anode and gate. (The diode in Fig. 1 protects the gate against the large reverse-bias voltages). With the reverse potentials, almost no current flows through the SCR. As the gate and anode voltages again become positive, the cycle repeats.

In Fig. 2(b), the value of $wC(R + R_2) \cong 1$. Then from equation (2), the gate voltage lags the applied voltage by 45^o. In the case, the gate will not permit the SCR to fire until the voltage across the load and the SCR has progressed 45o through the positive half-cycle. Thus, the current waveform has the shape shown in Fig. 2(b). Notice that the average value of this current waveform is less than the average value of the current waveform shown in Fig. 2(a). Since the power delivered to the load is $I_{rms}^2 R$, the power to the load is reduced as the conduction angle is increased (or as the firing angle is decreased).

In Fig. 2c, the value of $wC(R_1 + R_2) >> 1$. The gate voltage now lags the applied voltage by almost 90^o. In addition, the amplitude of the gate voltage is reduced to such a small magnitude that the gate will not fire until the gate voltage is almost at its peak value. (Note that there is a possibility that the gate will not fire at all if the peak value of the gate voltage is less than the firing voltage). Thus the gate fires when the applied voltage to the load and the SCR has almost reached the end of its positive half cycle. A short pulse of current flows and then ceases as the applied voltage to the load and SCR drops to approximately zero.

DESIGN EXAMPLE:

Let us design a light-dimmer circuit to handle a 100 W light globe. We shall use the circuit shown in Fig. 1. The SCR must be able to handle about 1A (current of the 100 W light) and block at least 185 V (the 120 V line may increase to 130 V with 185 V peak). Since the 2N3562 has a blocking voltage of 200 V and an average anode current of 1A (these data are available in the data sheet), it will be used. Curves of gate-cathode voltage versus gate current (available from manufacturer's data sheet) indicate typical 2N3562 devices have 1.3 V from the gate to cathode when the gate current is 150 mA. If the rms value of 1.3 V and 0.15 A are used, the average power dissipation would seem to be 195 mW. However, since this circuit is a half-wave circuit, the actual average dissipated power is really only 98 mW, which is below the allowable gate dissipation (100 mW as given in the data sheet). Maximum gate current flows when R1 is zero. Then the value of R_2 should limit the gate current to 0.15 A rms. The value of R_2 is 120 V/0.15 A = 800 Ω. To allow an extra safety margin, let us choose R_2=1kΩ.

To provide wide range of control, let us choose $wCR_2 << 1$ when $R_1 = 0$. with R_2=1kΩ, then C<<2.66μ F (notice that $\omega = 2\pi x6$rad/sec). Let us take C = 0.5 μF. Finally we require $wC(R_1 + R_2) >> 1$ when R_1 is fully in the circuit. Simple calculations shows that R_1 25kΩ is a reasonable choice.

The maximum reverse voltage permitted on the gate is 5 V , so the diode shown in Fig. 1 will be required. This diode must be able to withstand the total reverse voltage applied to the circuit as noted by Fig. 2. Thus the diode must have a reverse voltage rating greater than 185 V and must be able to pass a current equal to the maximum gate current (150 mA in this case) when forward biased.

The circuit shown in Fig.1 has one serious limitation. As you know the current will pass through the load only during the positive half cycle. Obviously a possible solution for this problem is to use the triac-based circuit shown in Fig. 3. Since the triac can switch from a blocking to a conducting state for either polarity of applied anode voltage and with either positive or negative gate triggering, the current through the load will have the waveform shown in Fig. 4. In this circuit, the current is controlled from zero to a full conduction value by adjusting R_1 through the proper range.

Most commercial circuits include a diac in the control circuit as shown in Fig. 5. Its function is to provide a sharp trigger pulse to the triac. As the voltage v_c across the capacitor increase from zero, as shown in Fig. 6, the diac will prevent trigger current from flowing to the triac until the voltage on C exceeds the trigger voltage, V_{trg} which is the sum of the diac's trigger voltage V_T, plus the triac's gate voltage, V_{GT}, or

$$V_{trg} = V_T + V_{GT} \tag{3}$$

The diac will then trigger, dumping almost all the charge on C into the gate of the triac. This sharp pulse reduces the triac's switching time. Thus it runs cooler than would otherwise be the case.

In order to do an exact analysis of the circuit of Fig. 5 the above very nonlinear components require the solution of a rather awkward differential equation. However, since the error introduced is not large, we can assume that steady state impedance relationships apply. Then if we ignore the load placed on the capacitor when the diac fires, the waveform of the voltage across the unloaded capacitor in Fig. 5 would be that of V_{Copen} of Fig 6(a). The actual voltage across the capacitor will be that shown in Fig. 6(b). With these approximations the analysis of the circuit of Fig. 5 will be similar to that of Fig. 1 except that the firing voltage here is equal to the sum of the firing voltage of the diac plus the gate voltage of the triac while for the circuit of Fig. 1 it is equal to the sum of one diode voltage plus the gate voltage of the SCR. A typical turn-on voltage for the 1N5758 diac is 19.6 V and a typical gate trigger voltage for the 2N6152 triac is 3V. Usually manufacturer data sheets gives maximum and minimum values of the diac turn-on voltage. For example for the 1N5758 diac the maximum turn-on voltage is 24 V and the minimum turn-on voltage is 16 V. The typical turn-on voltage can be calculated as the square root of the multiplication of these two limit values. Typical values for gate trigger voltages for SCR ranges from 2.5 V – 3.5 V for the triacs ranges from 3V-3.4 V.

EXPERIMENTAL WORK:

In the laboratory you will construct the circuits shown in Figs. 1 and 5. Check the waveforms at different points in the circuit and make sure that the firing angle is controllable by means of the variable resistor. Subject to availability, replace the load in Fig. 1 and 5 by a 100 W light globe. Check the operation of your light dimmers by means of the variable resistor.

BE CAREFUL YOU ARE DEALING WITH 120 V. BE CAREFUL

WRITE A REPORT SHOWING YOUR RESULTS. COMMENT ON THE PERFORMANCE OF THESE LIGHT DIMMERS.COMMENT ON ANY DISCREPANCIES BETWEEN THEORTETICAL AND PRACTICAL RESULTS

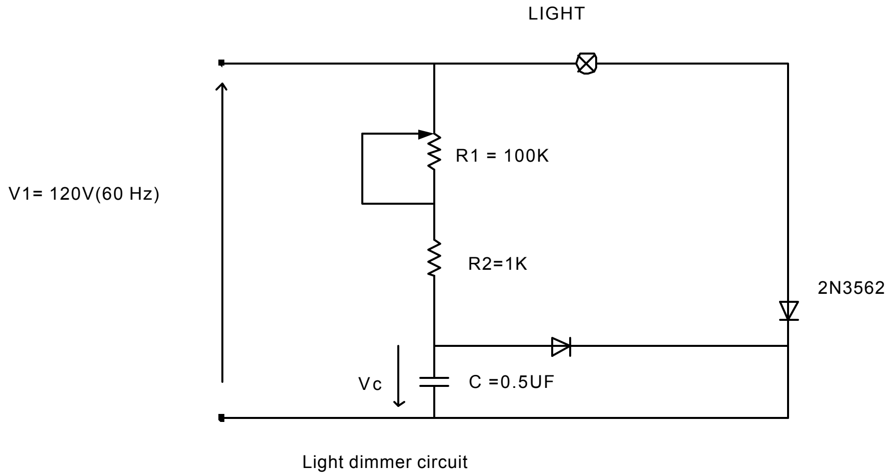


Fig.1: Light Dimmer (or Motor Speed Control) Circuit

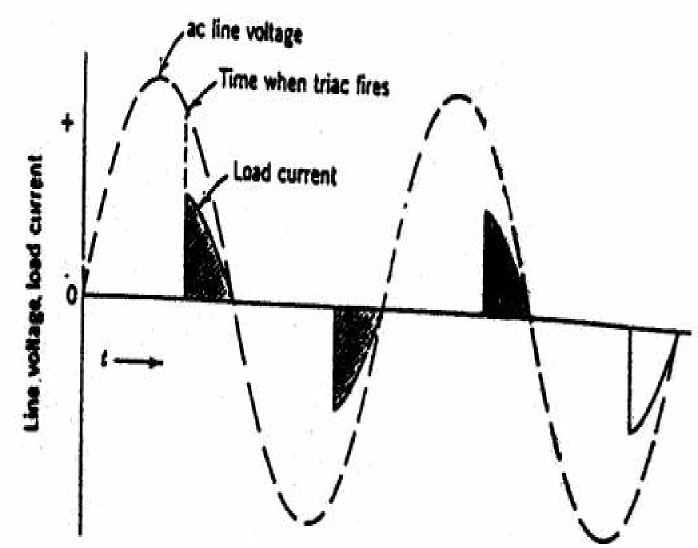


Fig. 4: Voltage and Current Waveform for the Circuit in Fig.3.

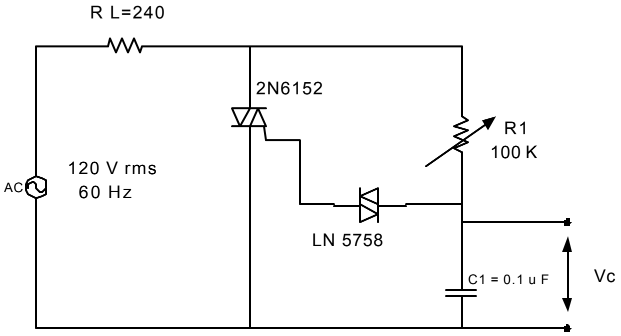
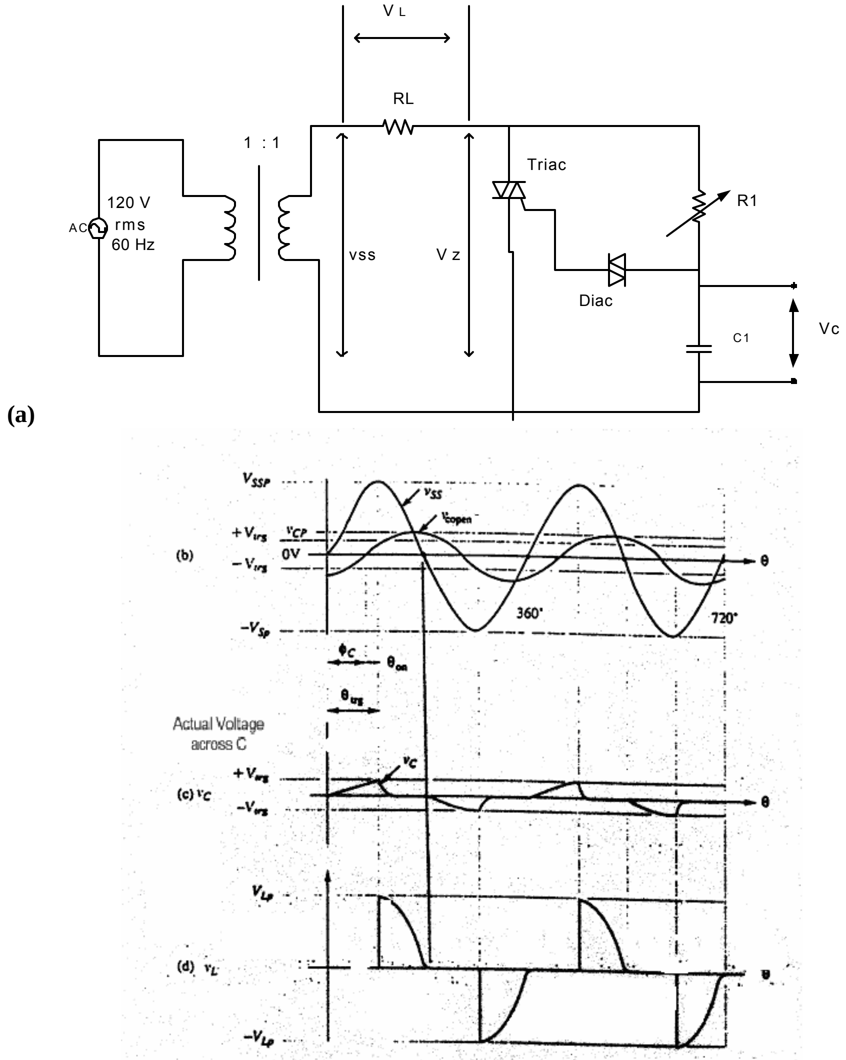


Fig.5: Commercial Dimmer Circuit



A simplified triac control circuit.
(a) Circuit diagram.
(b) Supply waveform and waveform that would exist at C_1 if it were not loaded.
(c) Waveform that actually exists across C_1.
(d) Output waveform.

Fig.6: A Simplified Triac Control Circuit and the Corresponding Input and Output Waveforms