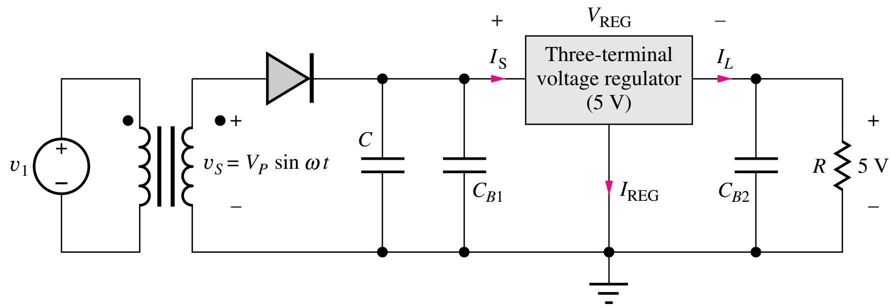

Figure 3.71 Half-wave rectifier and three-terminal IC voltage regulator.

Capacitor C is the normal rectifier filter capacitor, and C_{B1} and C_{B2} (typically 0.001–0.01 μf) are bypass capacitors that provide a low-impedance path for high-frequency signals and are needed to ensure proper operation of the voltage regulator.

The regulator can reduce the ripple voltage by a factor of 100 to 1000 or more. To minimize power dissipation in the regulator, the rectifier can be designed with a relatively large ripple voltage at the input to the regulator, thus reducing the average input voltage to the regulator. The main design constraint is set by the input-output voltage differential V_{REG} across the regulator, which must not fall below a minimum "dropout voltage" value specified for the regulator, typically a few volts. The current I_{REG} needed to operate the IC regulator is only a few mA and typically represents a small percentage of the total current supplied by the rectifier: $I_S = I_L + I_{REG}$. An example of a voltage regulator family can be found on the MCD website.

DESIGN EXAMPLE 3.13

RECTIFIER DESIGN FOR AN IC VOLTAGE REGULATOR

Here we redesign the rectifier from Ex. 3.12 to work with an IC voltage regulator. The filter capacitor value can be significantly reduced when we use the IC regulator.

PROBLEM Design a rectifier to provide a dc output voltage of 15 V with a load current of 2 A using an IC voltage regulator with a 15-V output. The IC voltage regulator requires an input-output voltage differential of at least 2 V for proper operation.

SOLUTION **Known Information and Given Data:** $V_{dc} = 15$ V regulated by a voltage regulator IC, $I_{dc} = 2$ A, $V_{REG} \geq 2$ V

Unknowns: Circuit topology, transformer voltage, filter capacitor, diode PIV rating, diode repetitive current rating, diode surge current rating

Approach: Use given data to evaluate rectifier circuit equations. Let us choose the full-wave bridge topology that requires a smaller value of filter capacitance, a smaller diode PIV voltage and no center tap in the transformer.

Assumptions: Assume diode on-voltage is 1 V. Assume a large ripple voltage at the input of the regulator, say 10 percent, to minimize C. Assume $I_{REG} \ll I_L = 2$ A.

Analysis: The required transformer voltage is now

$$V = \frac{V_P}{\sqrt{2}} = \frac{V_{dc} + V_{REG} + 2V_{on} + V_r}{\sqrt{2}} = \frac{15 + 2 + 2 + 1.5}{\sqrt{2}} \text{ V} = 14.5 \text{ V}_{rms}$$

Note that V can be larger than the value calculated here. The regulator's internal circuitry uses feedback that maintains a constant output voltage and causes any additional input voltage to appear across the regulator as an increase in V_{REG}.

The filter capacitor is found using the ripple voltage, output current, and discharge interval:

$$C = I_{dc}\left(\frac{T/2}{V_r}\right) = 2\,\text{A}\left(\frac{1}{120}\text{s}\right)\left(\frac{1}{1.5\,\text{V}}\right) = 11.1\ \mu\text{F}$$

To find I_P, the conduction time is calculated using Eq. (3.61)

$$\Delta T = \frac{1}{\omega}\sqrt{\frac{2V_r}{V_P}} = \frac{1}{120\pi}\sqrt{\frac{2(1.5)\,\text{V}}{20.5\,\text{V}}} = 1.02\ \text{ms}$$

and the peak repetitive current is

$$I_P = I_{dc}\left(\frac{2}{\Delta T}\right)\left(\frac{T}{2}\right) = 2\,\text{A}\frac{(1/60)\,\text{s}}{1.02\ \text{ms}} = 32.7\ \text{A}$$

The surge current estimate is

$$I_{\text{surge}} = \omega C V_P = 120\pi(0.0111)(20.5) = 85.8\ \text{A}$$

We must be concerned with the power dissipation in the voltage regulator. The power dissipation is equal to

$$P = I_S(V_{\text{REG}} + 15) - I_L(15) \cong I_L V_{\text{REG}} = 2\,\text{A}(2) = 4\ \text{W}$$

in which it has been assume that $I_S = I_L$. Note that the regulator will need to have an adequate heat sink to remove the 4 W.

The minimum diode PIV is $V_P = 20.5$ V. A choice with a safety margin would be PIV $= 25$ V. The repetitive current rating should be 35 A with a surge current rating of 90 A. Note that both of these calculations overestimate the magnitude of the currents because we have neglected series resistance of the transformer and diode. The minimum filter capacitor needs to be 11,000 μF. Assuming a tolerance of −30 percent, a nominal filter capacitance of 16,000 μF would be required.

Check of Results: The ripple voltage represents 10 percent of the rectifier output voltage. Thus the assumption that the voltage is approximately constant is justified. The conduction time is 1.03 mS out of a total period $T = 16.7$ mS. Thus the assumption that $\Delta T \ll T$ is satisfied.

Discussion: If we compare this design to that of Ex. 3.12, we see that the filter capacitor and diode current requirements are greatly reduced thus reducing the cost of these components. In exchange, we have added the cost of an integrated circuit voltage regulator but will have achieved much better output voltage control and significantly reduced ripple.

EXERCISE: Suppose the rectifier circuit from Ex. 3.13 was used with an IC voltage regulator with an output voltage of 10 V and a V_{REG} specification of 2 V. How large can the ripple voltage be permitted to be? What is the approximate value of filter capacitor C if $V_r = 5$ V?

ANSWERS: 6.5 V; 3300 μF