ENGR 305

Voltage Regulation

Rectifier Circuits

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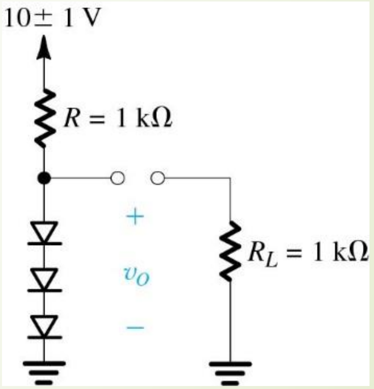
Voltage regulation

- A **voltage regulator** is a circuit designed to provide a constant dc voltage between its input and output terminals.
- The output voltage must remain as constant as possible in spite of
  - Changes in the load current from the regulator output terminal
  - Changes in the dc power supply that feeds the regulator circuit
- The forward-voltage drop of the diode remains almost constant at 0.7 V while the current varies by relatively large amounts
  - Thus, a forward-biased diode can make a simple voltage regulator.
- We can obtain regulated voltages greater than 0.7 V by connecting a number of diodes in series.

Voltage regulation – example 4.6

- Consider the circuit shown. A string of three diodes is used to provide a constant voltage of about 2.1 V.
- We want to calculate the percentage change in this regulated voltage caused by
  - (a) a $\pm 10\%$ change in the power-supply voltage
  - (b) connection of a 1-kΩ load resistance



Voltage regulation – example 4.6

- With no load, the nominal value of the current in the diode string is given by
  - $I = \frac{10-2.1}{1k\Omega} = 7.9\ mA$
- Each diode will have an incremental resistance of
  - $r_d = \frac{V_T}{I} = \frac{25\ mV}{7.9\ mA} = 3.2\ \Omega$
- The three diodes in series will have a total incremental resistance of
  - $r = 3r_d = 9.6\Omega$

Voltage regulation – example 4.6

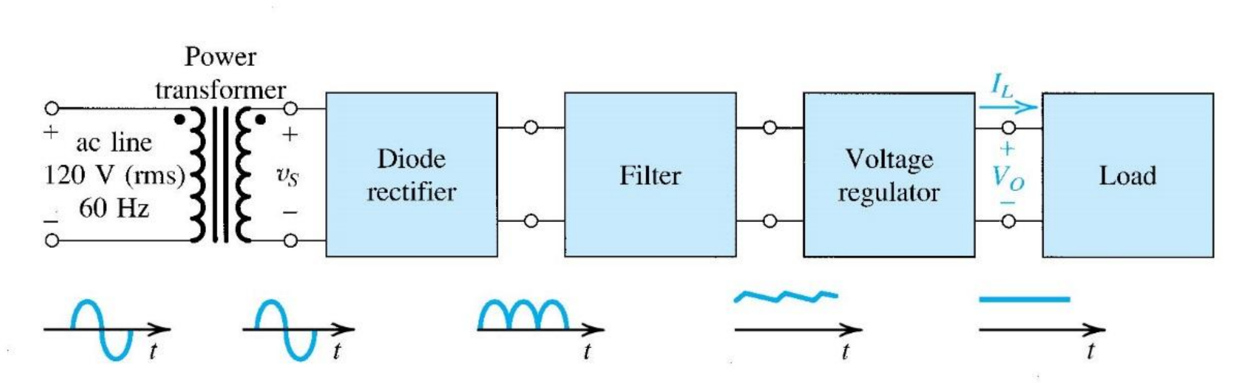
- This incremental resistance, along with the resistance *R*, forms a voltage divider whose ratio can be used to calculate the **change in output voltage** due to a $\pm 10\%$ $(\pm 1V)$ change in supply voltage.
- The peak-to-peak change in output voltage will be
  - $\Delta v_O = 2\frac{r}{r+R} = 2\frac{0.0096\ k\Omega}{0.0096\ k\Omega + 1k\Omega} = 19\ mV$
- Corresponding to the $\pm 1V$ $(\pm 10\%)$ change in supply voltage, the output will change by $\pm 9.5mV\ or\ \pm 0.5\%$.
- This implies a change of about ± 3.2 mV per diode, making our use of the small-signal model justified.

Voltage regulation – example 4.6

- Connecting a load resistance of 1 kΩ across the diode string, it draws a current of approximately 2.1 mA.
- The current in the diodes decreases by 2.1 mA, resulting in a decrease in voltage across the diode string given by
  - $\Delta v_O = -2.1 \times r = -2.1\, mA \times 9.6\ \Omega = -20\ \mathrm{mV}$
- This implies a voltage decrease across each diode of about 6.7 mV, which does not entirely justify use of the small-signal model.
- Yet, a detailed calculation of the voltage change using the exponential model yields $\Delta v_O = -23\, mV$, which is not significantly different from our result.

Rectifier circuits

- A diode rectifier forms an essential building block of the dc power supplies required to power electronic equipment.
- The power supply is fed from the 120-V (rms) 60-Hz ac line, and it delivers a dc voltage V_O.



Rectifier circuits

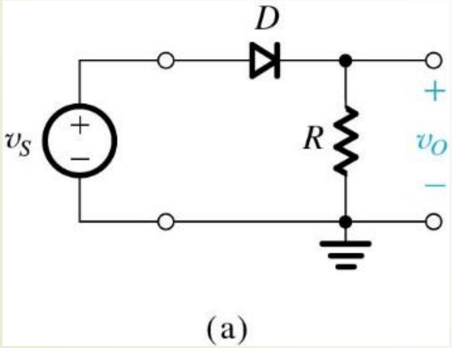
- The first block in a dc power supply is the **power transformer.**
  - It consists of two separate coils wound around an iron core that magnetically couples the two windings.
  - The **primary winding**, having N_1 turns, is connected to the 120-V ac supply.
  - The **secondary winding**, having N_2 turns, is connected to the circuit of the dc power supply.
  - An ac voltage v_S of $120\left({}^{N_2}/_{N_1}\right)$ V (rms) develops between the two terminals of the secondary winding.
- In addition to providing the appropriate sinusoidal amplitude for the dc power supply, the power transformer provides electrical isolation between the electronic equipment and the power-line circuit.

Rectifier circuits

- The *diode rectifier* converts the input sinusoid v_S to a unipolar output, which can have a pulsating waveform.
- Next, the variations in the magnitude of the rectifier output are considerably reduced by the *filter block*.
- The output of the rectifier filter, though much more constant than without the filter, still contains a time-dependent component, called **ripple.**
- To reduce the ripple and to stabilize the magnitude of the dc output against variations caused by changes in load current, we use a *voltage regulator*.

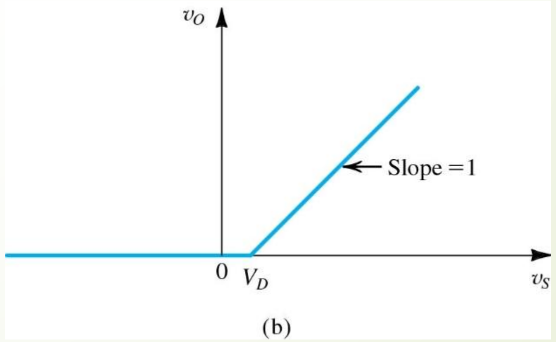
Half-wave rectifier

- The half-wave rectifier uses alternate half-cycles of the input sinusoid.
- We analyzed the circuit below previously.
- Now, using the constant-voltage-drop diode model



$0, v_S < V_D$

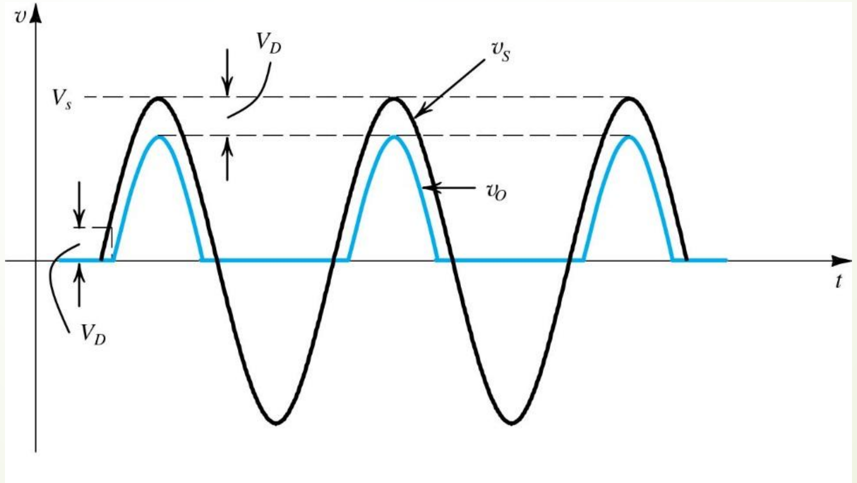
$v_S - V_D, v_S \geq V_D$



Transfer characteristic of the circuit

Half-wave rectifier

- We assume a forward voltage $V_D = 0.7\ V$
- The figure shows the output voltage when v_S is a sinusoid.



(c)

Half-wave rectifier

- Two important parameters that are specified in rectifier design
  - The current-handling capability of the diode or the largest forward current
  - The **peak inverse voltage** (PIV) that the diode must be able to withstand without breakdown
- The peak inverse voltage is determined by the largest reverse voltage that is expected to appear across the diode.
- In the half-wave rectifier circuit, when v_S is negative, the diode will be cut off.
- The PIV will then be equal to the peak of v_S
  - $PIV = V_S$
- It is a good idea in practice to select a diode that has a reverse breakdown voltage at least 50% greater than the expected PIV.