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lecture Five
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Diode Rectifier Circuits

Basic Definition:

A diode circuit that convert an ac voltage to a pulsating dc voltage and permits current to flow in one direction only is called " ***rectifier***" and the ac-to-dc conversion process is termed ***"rectification"***.

Half-wave rectifier [HWR]:

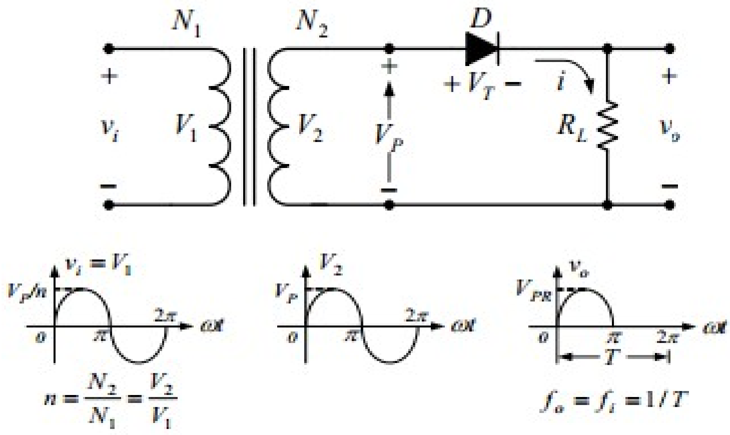


Fig. 5-1

❖ The average (dc) value of a half-wave rectified sine-wave voltage (V_{dc}) is

$$V_{dc}=\frac{1}{T}\int_0^T V_o(\omega t).d\omega t=\frac{1}{2\pi}\int_0^\pi V_{PR}\sin\omega t.d\omega t=\frac{V_{PR}}{\pi}$$

For V_P close to V_T ,

$$\boxed{V_{dc}=0.318(V_P-V_T)} \qquad [5\text{-}1a]$$

For $V_P \gg V_T$,

$$V_{dc}=0.318V_P \qquad [5\text{-}1b]$$

❖ The root mean square (rms) value of the load voltage (V_{rms}) is

$$V_{rms}=\sqrt{\frac{1}{T}\int_0^T V_o^2(\omega t).d\omega t}=\sqrt{\frac{1}{2\pi}\int_0^\pi V_{PR}^2\sin^2\omega t.d\omega t}=\frac{V_{PR}}{2}$$

For V_P close to V_T ,

$$\boxed{V_{rms} = 0.5(V_P - V_T)} \qquad [5\text{-}2a]$$

For $V_P \gg V_T$,

$$\boxed{V_{rms} = 0.5\,V_P} \qquad [5\text{-}2b]$$

- The rms value of the ac component (or ***the ripple voltage***) of the rectified signal [$V_r(rms)$] is

$$V_r(rms) = \sqrt{V_{rms}^2 - V_{dc}^2} = \sqrt{(0.5\,V_{PR})^2 - (0.381\,V_{PR})^2} = 0.385\,V_{PR}$$

For V_P close to V_T ,

$$\boxed{V_r(rms) = 0.385(V_P - V_T)} \qquad [5\text{-}3a]$$

For $V_P \gg V_T$,

$$V_r(rms) = 0.385\,V_P \qquad [5\text{-}3b]$$

- The percent ripple (r) in the rectified waveform (also called ***the ripple factor***) is

$$r = \frac{V_r(rms)}{V_{dc}} \times 100 = \frac{0.385\,V_{PR}}{0.381\,V_{PR}} \times 100 = 121$$

- Efficiency ($\eta) = [P_{dc}(load) / P_{total}(circuit)] \times 100$

$$\eta = \frac{I_{dc}^2 R_L}{I_{rms}^2 (r_d + R_L)} \times 100 = \frac{(0.318\,I_P)^2 R_L}{(0.5\,I_P)^2 (r_d + R_L)} \times 100 = \frac{40.5}{1 + r_d / R_L}$$

For ideal diode ($r_d = 0\,\Omega)$, $\eta = \eta_{max} = 40.5$,

- The peak inverse voltage (PIV) of the diode is

$$PIV = V_P \qquad [5\text{-}4]$$

- ❖ The frequency of the output rectified signal (f_o) is

$$f_o = f_i \qquad [5\text{-}5]$$

Full-Wave Rectifiers [FWRs]:

1. A Bridge Full-Wave Rectifier:

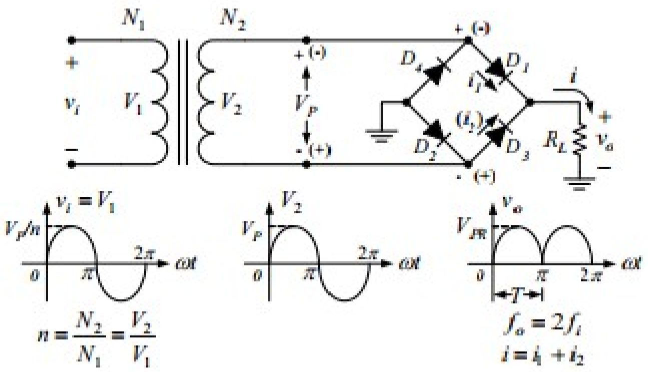


Fig. 5-2

:For the bridge full-wave rectifier circuit of Fig 5-2

- ❖ $V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_{PR} sin\omega t \, . d\omega t = \frac{2V_{PR}}{\pi}$

For V_P close to $2V_T$,

$$V_{dc} = 0.636(V_P - 2V_T) \qquad [5.6a]$$

For $V_P \gg 2V_T$,

$$V_{dc} = 0.636V_P \qquad [5.6b]$$

- ❖ $V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_{PR}^2 \sin^2\omega t \, . d\omega t} = \frac{V_{PR}}{\sqrt{2}}$

For V_P close to $2V_T$

$$V_{rms} = 0.707(V_P - 2V_T) \qquad [5.7a]$$

For $V_P \gg 2V_T$,

$$V_{rms} = 0.707V_P \quad (5.7b)$$

- ❖ $V_{r(rms)} = \sqrt{V_{rms}^2 - V_{dc}^2} = \sqrt{(0.707V_{PR})^2 - (0.636V_{PR})^2} = 0.308V_{PR}$

- ❖ For V_P close to $2V_T$,

$$V_r(rms) = 0.308(V_P - 2V_T) \quad (5.8a)$$

For $V_P \gg 2V_T$,

$$V_r(rms) = 0.308 V_P \quad (5.8b)$$

- $$r = \frac{V_r(rms)}{V_{dc}} * 100 = \frac{0.308 V_{PR}}{0.636 V_{PR}} * 100 = 48.4$$
- $$\eta = \frac{I_{dc}^2 R_L}{I_{rms}^2 (2r_d + R_L)} \times 100 = \frac{(0.636 I_P)^2 R_L}{(0.707 I_P)^2 (2r_d + R_L)} \times 100 = \frac{81}{1 + 2r_d / R_L}$$

For ideal diode ($r_d = 0\,\Omega)$, $\eta = \eta_{max} = 81$,

- The peak inverse voltage (*PIV*) of the diode is

$$PIV = V_P - 2V_T \qquad [5\text{-}9]$$

- The frequency of the output rectified signal ($f_o)$ is

$$f_o = 2 f_i \qquad [5\text{-}10]$$

2. A Center-Tapped [CT] Full-Wave Rectifier:

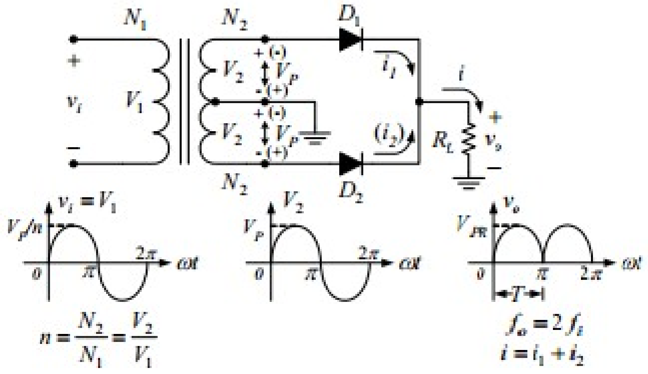


Fig. 5-3

For the center-tapped full-wave re... ...t of Fig. 5-3:

- $$V_{dc} = \frac{1}{\pi} \int_0^{\pi} V_{PR} \sin\omega t \, . d\omega t = \frac{2 V_{PR}}{\pi}$$

For V_P close to V_T ,

$$V_{dc} = 0.636(V_P - V_T) \qquad [5.11a]$$

For $V_P \gg V_T ,$

$$V_{dc} = 0.636 V_P \qquad [5.11b]$$

❖ $V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_{PR}{}^2 \sin^2 \omega t \, . \, d\omega t} = \frac{V_{PR}}{\sqrt{2}}$

For V_P close to V_T

$$V_{rms} = 0.707(V_P - V_T) \qquad [5.12a]$$

For $V_P \gg V_T ,$

$$V_{rms} = 0.707 V_P [5.12b]$$

❖ $V_r(rms) = \sqrt{V_{rms}{}^2 - V_{dc}{}^2} = \sqrt{(0.707V_{PR})^2 - (0.636V_{PR})^2} = 0.308V_{PR}$

❖ For V_P close to V_T ,

$$V_r(rms) = 0.308(V_P - V_T) [5.14a]$$

For $V_P \gg V_T ,$

$$V_r(rms) = 0.308V_P [5.13b]$$

❖ $r = \frac{V_r(rms)}{V_{dc}} * 100 = \frac{0.308V_{PR}}{0.636V_{PR}} * 100 = 48.4$

❖ $\eta = \frac{I_{dc}{}^2 R_L}{I_{rms}{}^2(r_d + R_L)} * 100 = \frac{(0.636I_P)^2 R_L}{(0.707I_P)^2(r_d + R_L)} * 100 = \frac{81}{1 + r_d / R_L}$

For ideal diode ($r_d = 0\,\Omega), \eta = \eta_{max} = 81$,

❖ The peak inverse voltage (*PIV*) of the diode is

$$PIV = 2V_P - V_T \qquad [5\text{-}14]$$

❖ The frequency of the output rectified signal ($f_o)$ is

$$\boxed{f_o = 2 f_i} \qquad [5\text{-}15]$$

Summary:

Different parameters for the HWR and FWR circuits are listed in Table 5-1.

parameter	HWR	FWR	
		Bridge	CT
V_{PR}	$V_P - V_T$	$V_P - 2V_T$	$2V_P - V_T$
V_{dc}	$0.318 V_{PR}$	$0.636 V_{PR}$	
V_{rms}	$0.5 V_{PR}$	$0.707 V_{PR}$	
V_r	$0.385 V_{PR}$	$0.308 V_{PR}$	
r	121%	48.4%	
η_{max}	40.5%	81%	
PIV	V_P	$V_P - 2V_T$	$2V_P - V_T$
f_o	f_i	$2f_i$	

Table 5-1

Example 5-1:

The input voltage to a full-Wave rectifier employing a center-tapped step-down transformer and two silicon diodes is 220V rms, and the transformer has turns ratio $n=0.125$. Draw the rectifier circuit diagram when it is connected to a 100Ω load, and find

1. The average value of the voltage across the load.
2. The average power dissipated by the load, and
3. The minimum *PIV* rating required for each diode.

Solution:

The rectifier circuit diagram is shown in Fig, 5-4.

1. $V_P = \sqrt{2} V_i n = \sqrt{2} * 220 * 0.125 = 38,9 V.$

$V_{dc} = 0.636(V_P - V_T) = 0.636(38.9 - 0.7) = 24.3 V.$

2. $V_{rms} = 0.707\left(V_P - V_T\right) = 0.707\left(38.9 - 0.7\right) = 27.0\,V.$

$$P_{av} = \frac{{V_{rms}}^2}{R_L} = \frac{\left(27.0\right)^2}{100} = 7.3\,W.$$

3. $PIV \geq \left(2V_P - V_T\right) = \left(2 * 38.9 - 0.7\right) = 77.1\,V.$

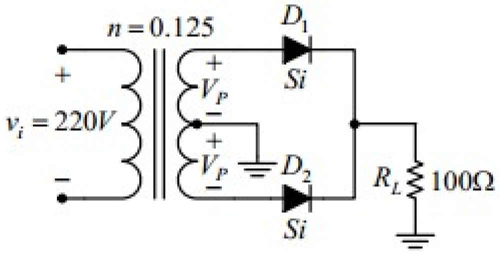
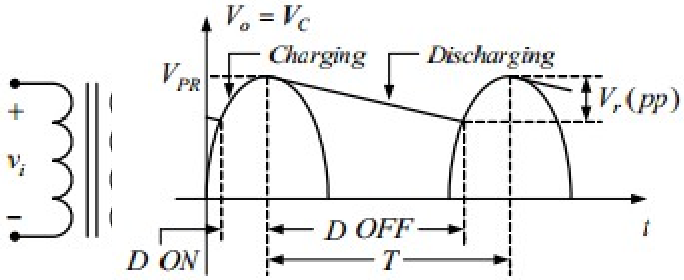


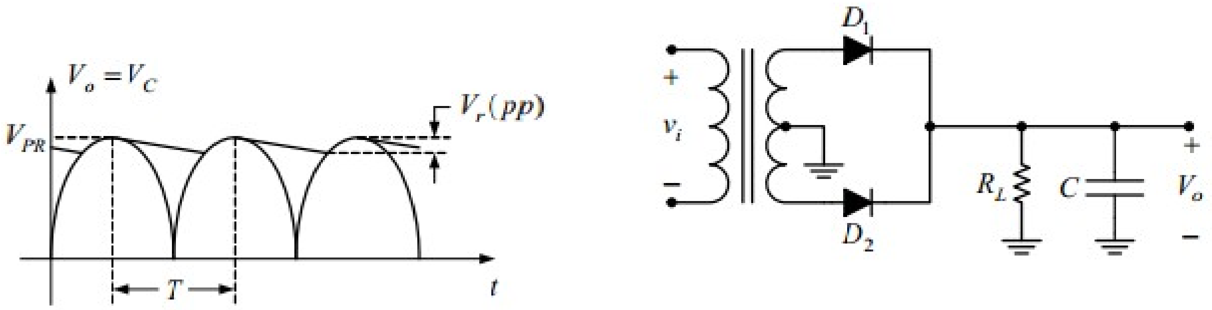
Fig. 5-4

:Capacitor filters

A low-pass filter is connected across the output of a rectifier to suppress the ac components and to pass the dc component. A rudimentary low-pass filter used in power supplies consists simply of a capacitor (c) connected across the rectifier output, that is in parallel with the load R_L , as illustrated in Fig. 5-5.



Half-Wave rectifier with capacitor filter



Full-Wave rectifier with capacitor filter

Fig. 5-5

:Operation

- During the Positive first quarter –cycle of the input, the diode is forward-biased (when V_i ⊛ V_c ◷ , allowing the capacitor to charge quickly to within a diode drop of the input peak (V_{PR} ◷ .
- When the input begins to decrease below it its peak, the capacitor retain its charge and the diode becomes reverse-biased (when V_i ⊛ V_c ◷ ,
- During the remaining part of the cycle, capacitor *c* can discharge slowly only through load resistance R_L at a rate determine by $R_L c$ time constant (τ ◷ .

- The voltage fluctuation in the filtered waveforms is called the peak ripple voltage $(V_r(pp))$. in general, $V_r(pp)$ in FWR is smaller than it is in HWR for same R_L and c values (see Fig. 5-5).

Ripple Of Capacitor Filter:

We will now derive an expression for the ripple in the output of a rectifier having a capacitor filter (C) and load resistance R). The derivation that follows is applicable to both HWR and *htly loaded filter* R time constant n Fig. 5-6.

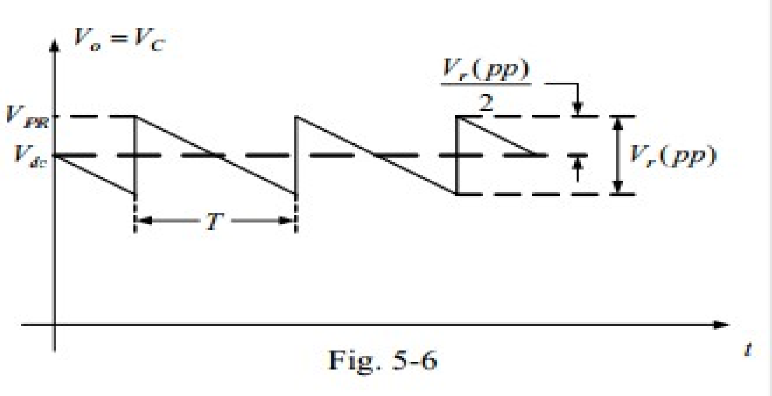


Fig. 5-6

Fig. 5-5

This approximation is equivalent to assuming that the capacitor charges instantaneously and that its voltage decays linearly, instead of exponentially. Assuming that the voltage decays linearly is equivalent to assuming that the discharge current (I) is constant and equal to $I = V_{dc}/R_L$ where V_{dc} is the dc value of the filtered waveform. The total charge in capacitor voltage is $V_r(pp)$ volts, and this charge occurs over the period of time T.

Therefore , since $\Delta Q = I.\Delta t$,

$$V_r(pp) = \frac{\Delta Q}{C} = \frac{(V_{dc}/R_L)T}{C}$$

Since $T = 1/f_r$, where is the frequency of the fundamental component of the ripple, that is, $f_r = f_o = f_i$ for HWR and $f_r = f_o = 2f_i$ for FWR. So that

$$V_r(pp) = \frac{V_{dc}}{f_r R_L C} \qquad [5.16]$$

Or

$$V_{dc} = V_r(pp) \cdot f_r R_L C \qquad [5.17]$$

From Fig. 5-6, it is apparent that

$$V_{dc} = V_{PR} - \frac{V_r(pp)}{2}$$

Subsuming from Eq.[5.16][, we obtain

$$V_{dc} = V_{PR} - \frac{V_{dc}}{2 f_r R_L C}$$

Solving for V_{dc}, we obtain an expression for the dc voltage (V_{dc}) in terms of the peak rectifier voltage (V_{PR}):

$$V_{dc} = \frac{V_{PR}}{1 + \frac{1}{2 f_r R_L C}} \qquad (5.18)$$

The rms value of a saw tooth waveform having peak-to-peak value $V_r(pp)$ is known to be

$$V_r(rms) = \frac{V_r(pp)}{2\sqrt{3}} \qquad (5.19)$$

Therefore, from Eqs. [5.17] and [5.19], the percent ripple is

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$$r = \frac{V_r(rms)}{V_{dc}} * 100 = \frac{V_r(pp)/(2\sqrt{3})}{V_r(pp)\, f_r R_L C} * 100$$

$$\boxed{r = \frac{1}{2\sqrt{3}\, f_r R_L C} * 100 \quad (5.20)}$$

Equation [5.20] confirms our analysis of the capacitor filter: a large $R_L C$ time constant (τ) result in a small ripple voltage, and vice versa. The light-load assumption on which our derivation is based is generally valid for present ripple (r) less than 6.5%. From a design standpoint, the values of f_r and R_L , are usually fixed, and the designer's task is to select a value of C that keeps the ripple below a prescribed value.

Example 5-2:

A full-wave rectifier is operated from a 50Hz line and has a filter capacitor connected across its output. What minimum value of capacitance is required if the load is $1.2\,K\Omega$ and the ripple must be no greater than 2.4% ?

Solution:

$$r = \frac{1}{2\sqrt{3}\, f_r R_L C} * 100$$

$$0.024 = \frac{1}{2\sqrt{3} * 2 * 50 * 1.2 * 10^3 * C}$$

$$C \geq 100\,\mu F\,.$$

Exercises:

1. A full-wave bridge rectifier isolated from the 220 V rms power line by a transformer. Assuming the diode voltage drop are 0.7 v.

i. What turns ratio should the transformer have in order to produce an average current of 1A in a 10Ω load?
ii. What is the average current in each diode under the condition of (i)?
iii. What minimum *PIV* rating should each diode have?
iv. How much power is dissipated by each diode?

2. A full-wave bridge rectifier is operated from a 50Hz, 220 v rms line. It has a 100µF filter capacitor and a 2KΩ load. Neglect diode voltage drops.
i. What is the percent ripple?
ii. What is the average current in the load?