Power Electronics

3rd Year

2023 / 2024

Chapter 3
POWER RECTIFIERS

Prepared by:

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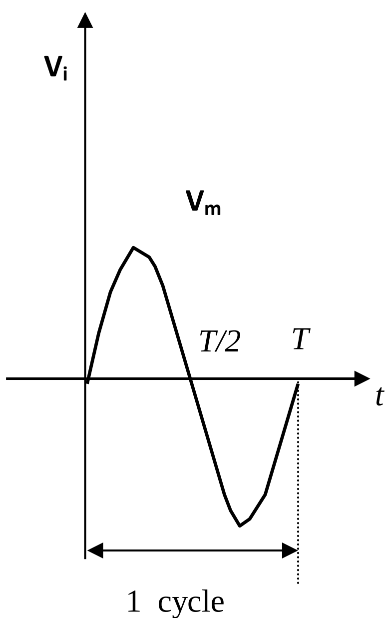
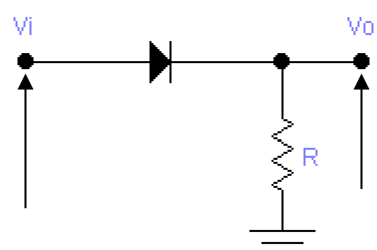
7.1 HALF – WAVE RECTIFIER

- Half – wave rectifier: It is the process of removing one half the input signal to establish a dc level. The term rectification comes from the use of the term rectifier for diode employed in power supply for ac to dc conversion process
- The circuit of fig (7-1) called a half wave rectifier will generate a wave from V_0 that will have an average value of particular use in the ac – to – dc conversion process.
- Ideal model for diode will be used for simplicity.



$V_i = V_m \sin w_m t$



Fig(7-1)

- During the interval t = 0 → T/2 in Fig (7-1) the polarity of the input voltage V_i is shown in Fig (7-2). The output voltage is contacted directly to the input, with the result that for period 0 → T/2 ,$V_0 = V_i$.

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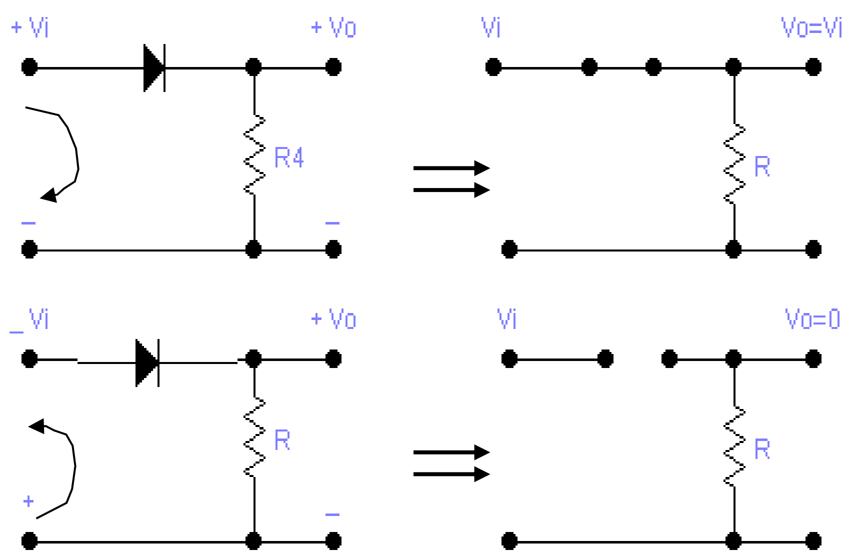
❖ For period T/2 →T ,the polarity of the input voltage V_i is shown in Fig(7-3) and the ideal diode produces in off state,V_0 =0V. The input voltage V_i and output voltage is shown in Fig (7-4).



Fig(7-2)

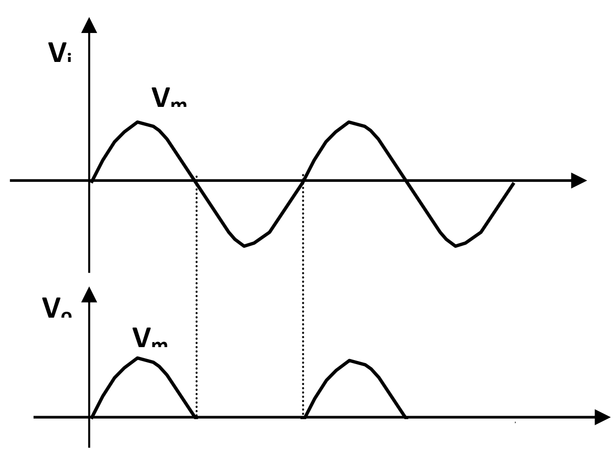
Conducting

region

Fig(7-3) Non

Conducting

region



Fig(7-4) half wave Rectifier

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❖ The output signal V_0 now has a net positive area above the axis over a full period and an average value determined by :

$$\text{average } (V_{dc} \text{ value}) = 0.318 V_m \ .$$

❖ The effect of using a silicon a idea with V_T =0.7V is shown by Fig (7-5) for the forward bias. The input must now be at least 0.7V before the diode conducts.

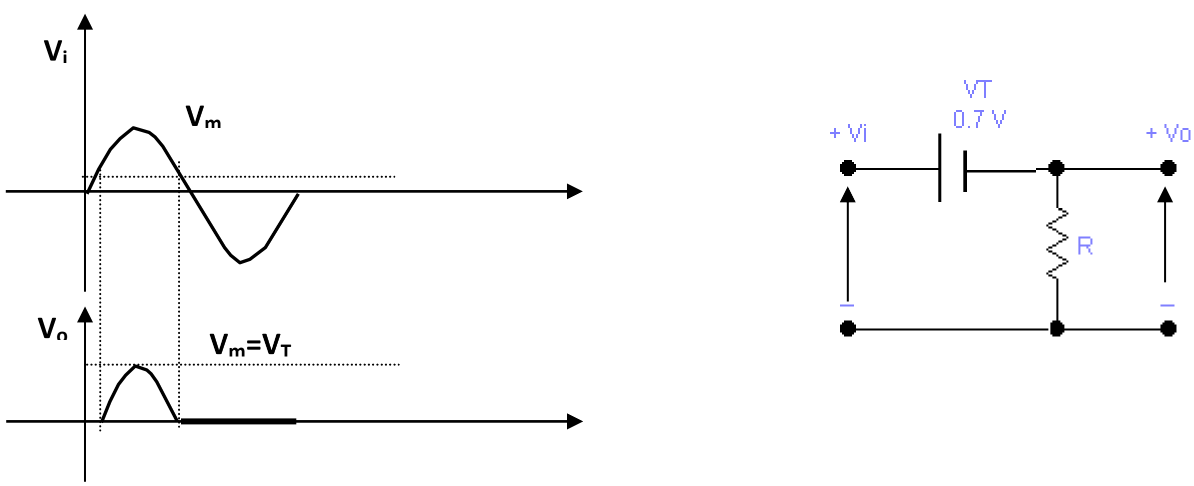
❖ When conducting:

$V_0 = V_i - V_T$.

$Vdc = 0.318 \, (V_m - V_T)$.

If $V_m >> V_T$

$\therefore Vdc = 0.318 \, V_m \Big|_{V_m \rangle\rangle V_T}$

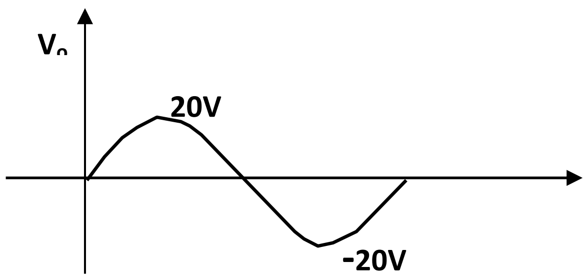


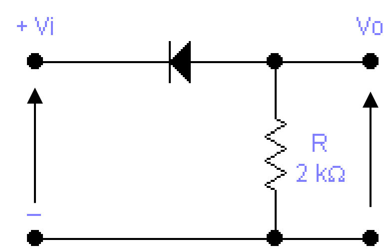
Fig(7-5)

EXAMPLE 7.1

A- Sketch the output V_0 and determine the dc level of the output for the network of Fig(7-6).

B- Repeat part (A) if the ideal diode is replaced by a silicon diode.





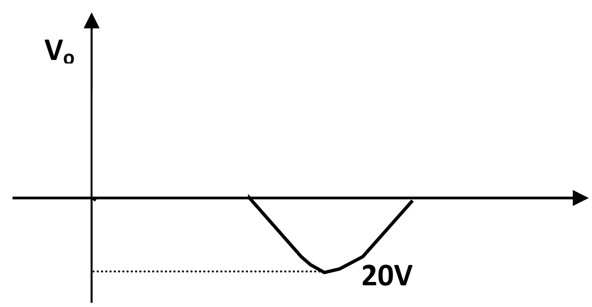
Fig(7-6)

SOLUTION

A- In this situation the diode will conduct during the negative part of the input as shown in the Fig below

$V_{dc} = -0.318V_m$

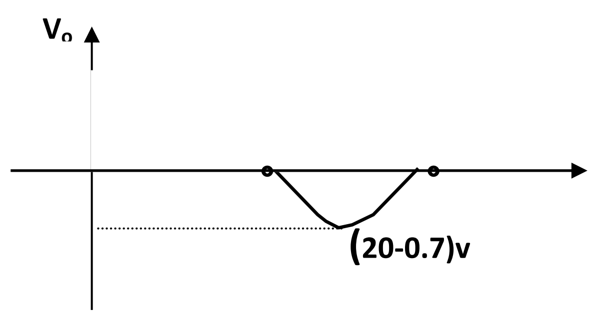
$= -0.318(20) = -6.36V$



B- Using A silicon diode, the output shown in fig below

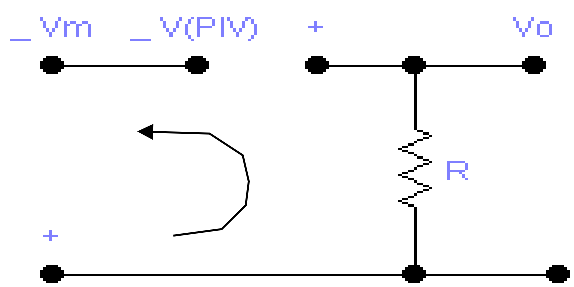
$\therefore V_{dc} = -0.318(V_m - V_T)$

$= -0.318(20-0.7)$



The peak – inverse voltage (PIV) rating of diode is voltage rating that must not be exceeded in the reverse bias region, or the diode will enter the Zener breakdown region. The required PIV rating for the half wave receiver can be shown in Fig(7-7), it is obvious PIV rating of the diode must equally or exceed the peat value of the input voltage.

$PIV_{rating} = V_m$ rating for half wave rectifier



Fig(7-7)

9-1 FULL – WAVE RECTIFICATION

The dc level obtained from a sinusoidal input by half wave rectifier can be improved 100% using a process called Full Wave Rectification four diodes in a bridge configuration can be used full wave rectifier as shown in Fig (9-1)

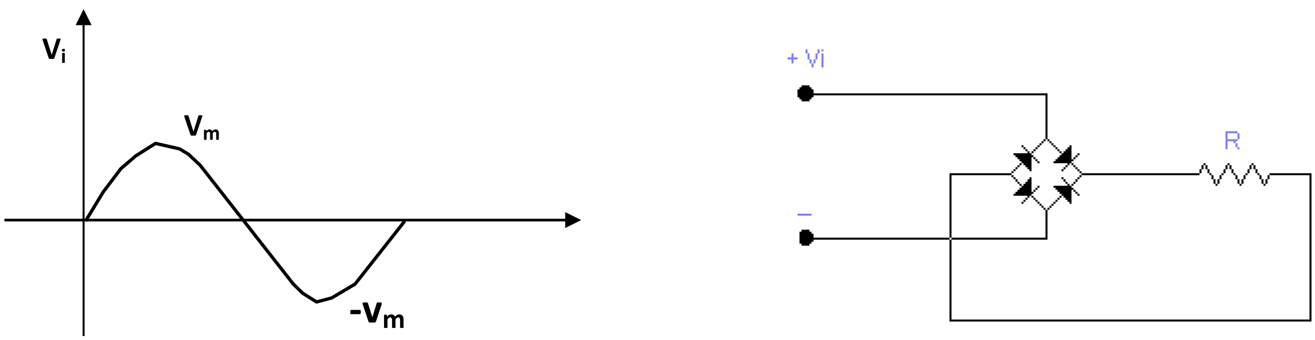
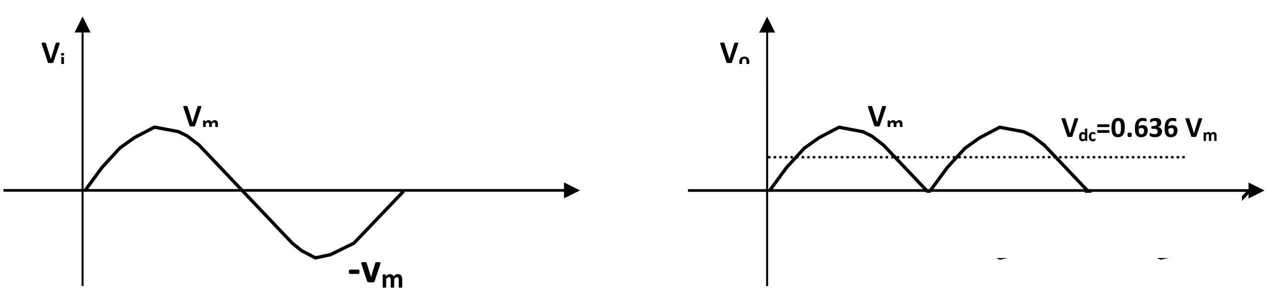


Fig (9-1)

- For the positive region of the input the conducting diodes are D_2 and D_3 while D_1 and D_4 are in the off state.
- For the negative region of the input the conducting diode are D_1 and D_4 while D_2 and D_3 are in the off state.
- The dc level for full wave rectifier is twice that optioned for for a half wave system

∴ average (dc) level = 0.636 V_m

and over one full cycle the input and output voltage is shown in Fig(9-2).



Fig(9-2)

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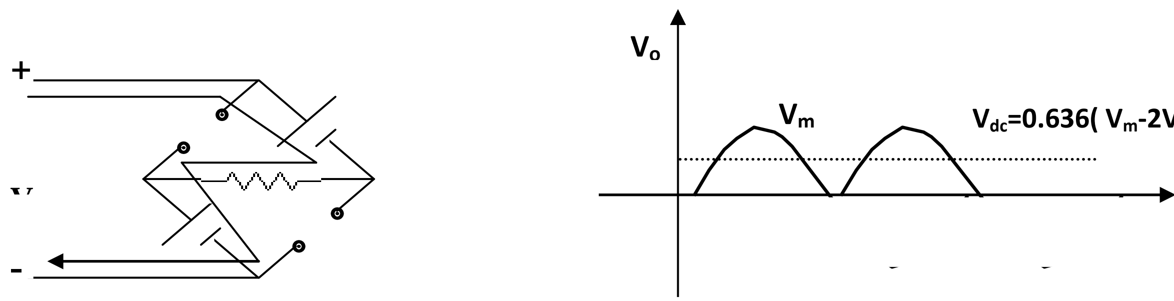
The effect of V_0 has also doubled as shown in Fig(9-3) for silicon diode during the conduction state (for positive region)

$\therefore V_{dc} = 0.636 V_m \Big|_{V_m >> 2V_T}$ and if V_m is close to $2V_T$ $\therefore V_{dc} = 0.636\,(V_m - 2V_T)$



Fig(9-3)

A second popular full wave rectifier used only two diodes but requiring a center tapped (CT) to establish the input signal across each section of the secondary of the transformer as shown in Fig (9-4).

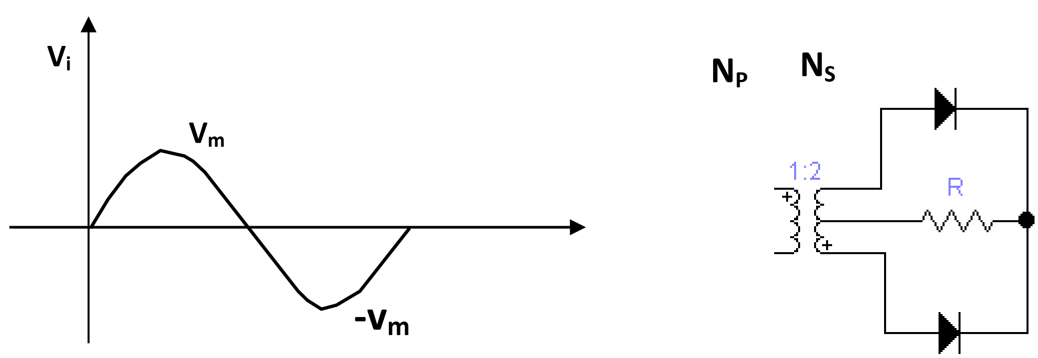


Fig (9-4)

$$N_P/N_S = V_P/V_S$$

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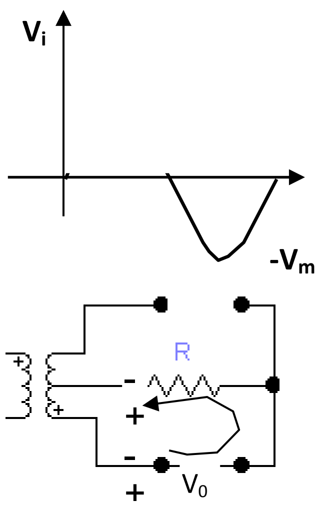
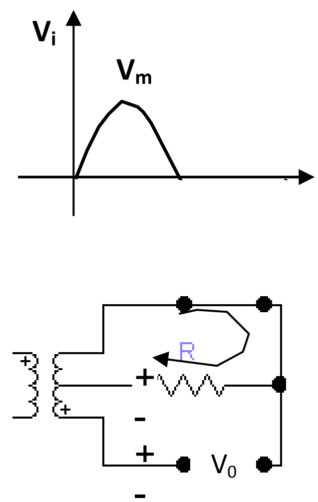
- ❖ During the positive portion of V_i applied to the transformer the diode D_1 is short circuit and the diode D_2 is open circuit.
- ❖ During the negative portion of V_i applied to the transformer, the diode D_1 is open circuit and the diode D_2 is short circuit as shown in Figure.



For -ve region



For +ve region

❖IV (peak inverse voltage) for each diode for this full wave rectifier can be determined from Fig(9-5).

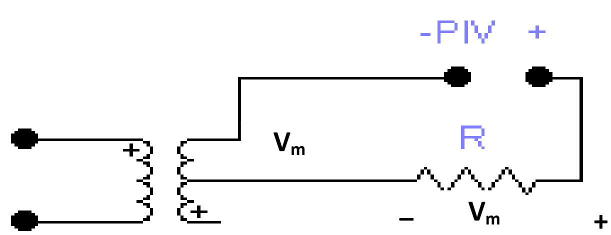


Fig (9-5)

- ❖ Inserting the maximum voltage for the secondary voltage then

$PIV = V_{Secondary} + V_R$

$PIV = V_m + V_m = 2V_m$ (For transformer full wave rectification)

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EXAMPLE 4.1

Determine the output waveform for the network of Fig (9-6) and calculate the output dc level and the required PIV of each diode.

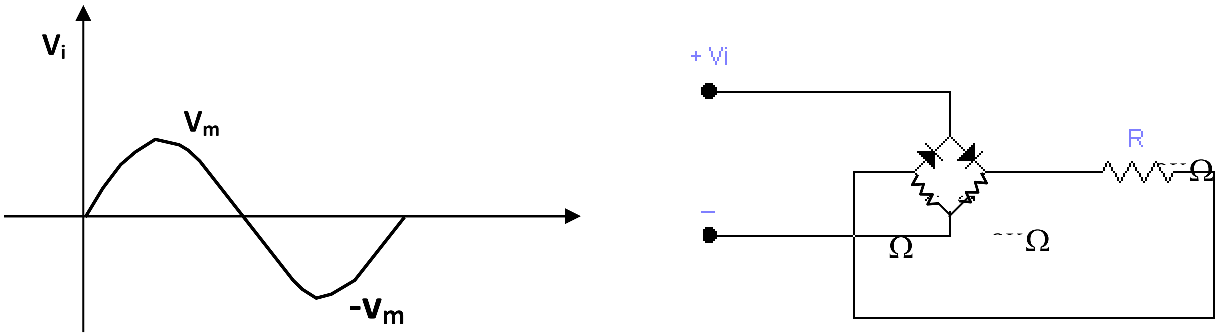

Fig (9-6)

SOLUTION

The network will appear as shown in Fig (9-7) for +ve region of the input voltage .

D_1 is on , D_2 is off

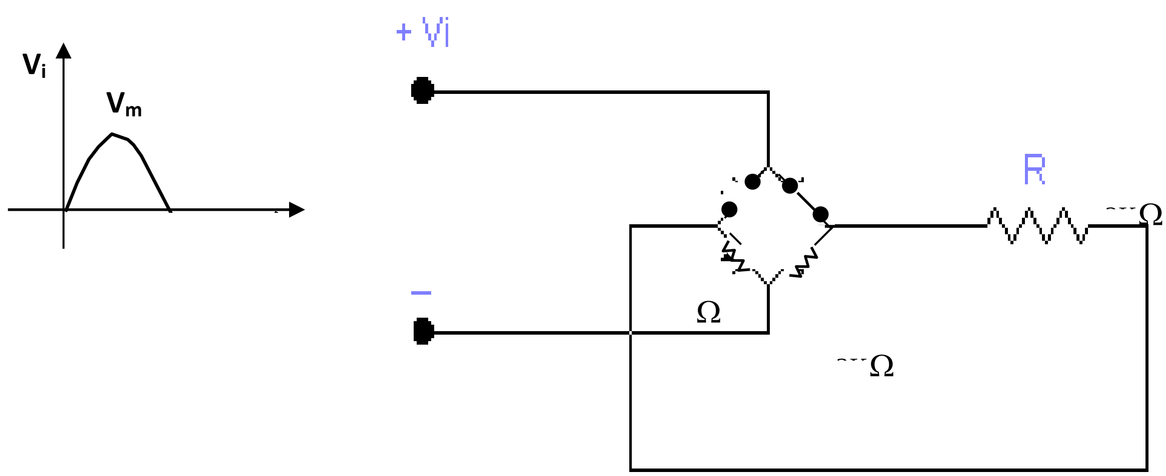

Fig (9-7)

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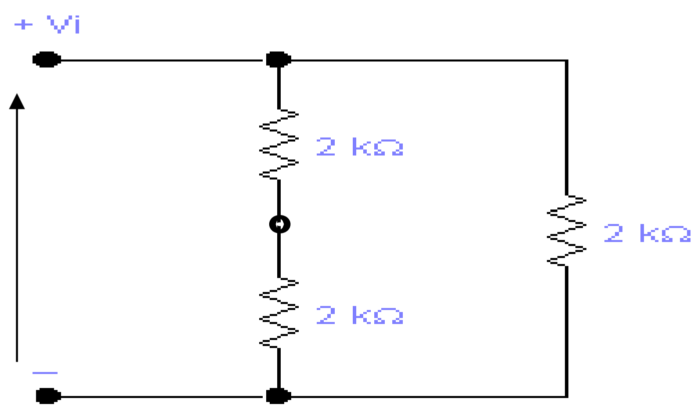
- Redrawing the network will result in the configuration of Fig (9-8)Where

  $V_0 = (1/2)V_i$

  $V_0\ max = (1/2)V_i\ max = (1/2)(10) = 5V$

- During the negative, reversing the roles of diodes (D_1 is off and D_2 is on).

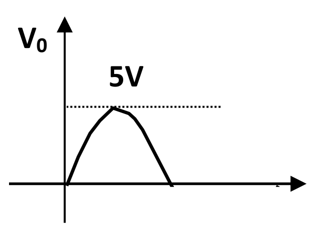
The effect of removing two diode from the bridge configuration was therefore to



reduce the available dc level to the following

$V_{dc} = 0.636(5) = 3.18\ V$

Fig (9-8)



For +ve region

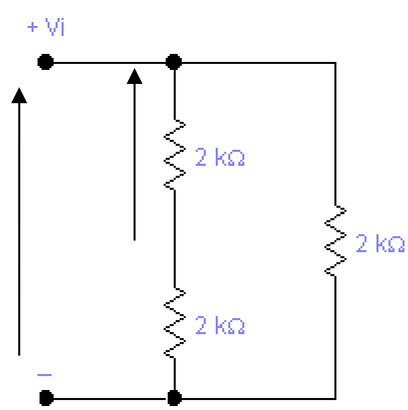


Fig (9-8)

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V_0 is shown in Fig (9-9)

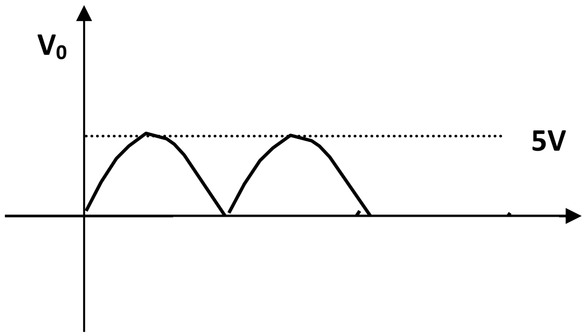

Fig (9-9)

The PIV is equal to the maximum voltage across R , which is (5V).

12.1 POWER SUPPLICES AND VOLTAGE REGULATORS

The term power supply generally refers to a source of (dc) power that is itself operated from source (ac) power. This type can therefore be regarded as an ac to dc converter. A (dc) power supply operated from an (ac) source consists of one or more of the following fundamental components, as shown in Fig (12-1) :

- ❖ A rectifier that convert an ac voltage to pulsating dc voltage and permits current to flow in one direction only.
- ❖ A low pass filter that suppresses the pulsation in the rectified wave form and passes its dc (average value) component.
- ❖ Voltage regulator that maintains a constant output voltage under variations in the load current drawn from the supply and under variations in line voltage.
- ❖ power supplies are classified as regulated or unregulated and adjustable or fixed.

Fig (12-1) Block diagram showing part of power supply

12.2 FILTER VOLTAGE REGULATION AND RIPPLE VOLTAGE

The Filter output voltage of Fig(12-2) has a dc value and some ac variation (ripple). The smaller the ac variation with respect to the dc level the better the filter circuit operation. Consider measuring the output voltage of the filter circuit using a dc voltmeter and ac (rms) voltmeter. The dc voltmeter will read only the average or dc

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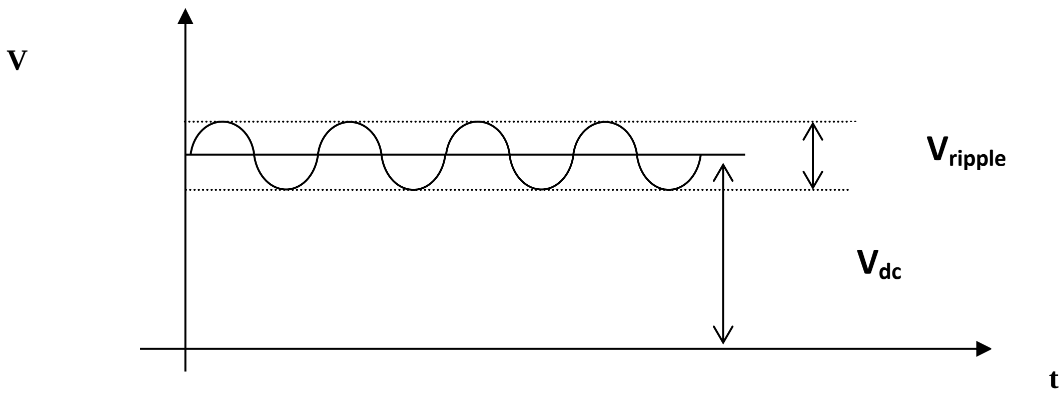
level of the output voltage. The ac (rms) meter will read only the (rms) value of the ac component of the output voltage (assuming the signal is coupled to the meter through a capacitor to block out the dc level).



Fig(12-2) filter output voltage

Ripple = ripple voltage (rms) / dc voltage

$=V_r\ (rms) / V_{dc} \times 100\%$

EXAMPLE 12.1

Using a dc and ac voltmeter to determine the output signal from a filter circuit, a dc voltage of 25V and ac ripple voltage of 1.5V rms are obtained. Calculate the ripple of the filter output.

SOLUTION

$r = V_r\ (rms) / V_{dc} \times 100\ \%$

$$r = \frac{1.5V}{25V} = 6\ \%$$

12.3 VOLTAGE REGULATION

The second factor of importance in a voltage supply is the amount of change in the output dc voltage over the range of the circuit operation. The voltage at the output at no-load (no current drawn from the supply) is reduced when load current is drawn from the supply. This voltage change is described by a factor called voltage regulation is given by :-

Voltage Regulation = voltage at no load – voltage full load / voltage at full load

$$V.R.= \frac{V_{NL-}V_{FL}}{V_{FL}} \times 100\%$$

EXAMPLE 6.2

A dc voltage supply provided 60V when the output is unloaded. When full load current is drawn from the supply, the output voltage drops to 56V . calculate the value of voltage regulation.

SOLUTION

$$V.R.= \frac{V_{NL-}V_{FL}}{V_{FL}} \times 100\%$$

$$V.R. = \frac{60V - 56V}{56V} \times 100\% = 7.14\%$$

12.4 RIPPLE FACTOR OF RECTIFIED SIGNAL

Although the rectified voltage is not a filtered voltage, it never the less contains a dc component and a ripple component. We can calculate these values of dc voltage and ripple voltage (rms) and them obtain the ripple factor for the half – wave and full – wave rectified voltages. Half wave rectified signal the ripple factor of a voltage is defined by r = rms value of ac component / average value of signal

$r = V_r(rms) / V_{dc}$

The rms value of the ac component is

$V_r(rms) = 0.385\ V_m$

$$\therefore\ r = \frac{V_r(rms)}{V_{dc}} = \frac{0.385V_m}{0.318V_m} \times 100 = 1.21 \times 100 = 121\%$$

Full wave rectified signal

$V_r(rms) = 0.308\ V_m$

$$\therefore\ r = \frac{0.308V_m}{0.636V_m} \times 100 = 48\%$$

NOTE

The root mean square (rms) value of the instantaneous values of current (voltage) over one complete cycle is (even the value over half a cycle will do)

$$I_{rms} = \left(\frac{I_m^2}{2}\right)^{\frac{1}{2}} = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

The average value in the case of a symmetrical alternating current (voltage) over a complete cycle is zero. Hence, the average value in this case can be obtained by integrating over half cycle (the instantaneous values of current (voltage).

$$I_{av} = \frac{2I_m}{\pi} = 0.636 I_m$$

12.5 CAPACITOR

The ripple factor value for full and half wave rectifiers are quite large (121% and 48.% as shown in equations above) and demonstrate the need for a filter in most power supply applications. If a filter is not used, the ac component of the ripple are superimposed on the signal lines in the device that receives power from the supply. Power supply ripple is therefore a source of noise in an electronic system.

The frequency of the fundamental component of half wave rectified waveform is the same as the frequency of its original (un rectified) ac waveform either 50 or 60 HZ depend on ac power source, plus harmonic components that are integer multiplies of 50 and 60 HZ. A full wave rectifier waveform has one half the period of a H-W rectified waveform, so it has twice the frequency (100 and 120 HZ plus harmonics).

A low pass filter is connected across the output of a rectifier to suppress the ac component and pass the dc component. A low pass filter used in power supplies consists simply of a capacitor connected across the rectifier output, that is in parallel with the load. Shown in Fig (12-3). The forward resistance of diode is small in comparison to R_L , so during the positive half cycle, the capacitor charges to the peak value of ac input.

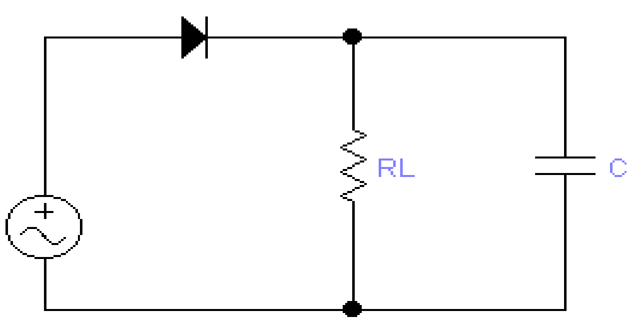
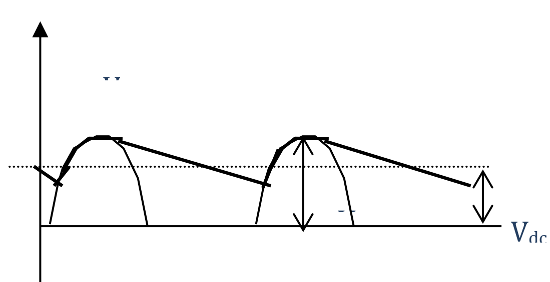
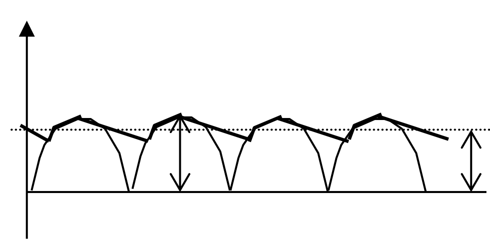


Fig (12-3)

Fig(12-4)and Fig(12-5) show how the capacitor charge and discharges during the full cycle of the ac input. The smaller the RC time constant, the further the capacitor or voltage decays be for another positive pulse arrives and recharge the capacitor.



Fig(6-4)



Fig(6-5)

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The small RC result in an undesirably large ripple voltage. Let us consider the capacitor voltage does not decay significantly from its peak value between the occurrences of the rectified pulses that recharge the capacitor. This case is called light loading because the charge supplied to R_L by the capacitor is small compared to the total charge stored on the capacitor. To simplify the computations, we can assume the ripple voltage in a slightly loaded filter is a saw tooth wave as shown in Fig (12-6). This assume is equivalent to assuming that the capacitor charges instantaneously and the voltage decays linearly, instead of exponentially. Assuming that the voltage decays discharge current ($I_{discharge}$) is constant.

Where f_r = frequency of the fundamental component of the ripple (typically 60 or 50 , 120 or 100 HZ).

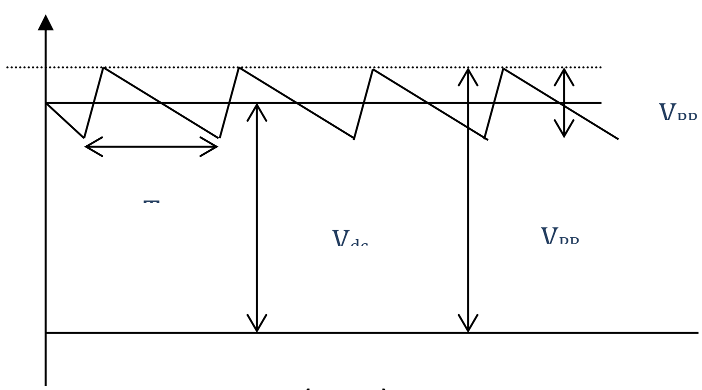
$$V_{dc} = V_{pp}\, f_r\, R_L\, C$$

From Fig (12-6)

$$V_{dc} = V_{PR} - V_{pp} / 2$$

Substituting from last equation , we obtain

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



Fig(12-6)

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$$V_{dc} = \frac{V_{PR}}{1+\frac{1}{2 f_r R_L C}}$$

Where:

$V_{PR} = V_m$

$$V_{dc} = \frac{V_m}{1+\frac{1}{2 f_r R_L C}}$$

The rms value of a saw tooth waveform having peak value V_{pp} is given by

$$V_{(rms)} = \frac{V_{pp}}{2\sqrt{3}}$$

Therefore, from above equations , the ripple factor is

$$r = \frac{V_{rms}}{V_{dc}} \times 100 = \frac{V_{pp}/2\sqrt{3}}{V_{pp} f_r R_L C} \times 100$$

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

Thus, large ($R_L C$) time constant results in a small ripple voltage. The above derivation is applicable to both H.W and F.W rectifiers provided the assumption of light loading.

EXAMPLE 12.3

A full wave rectifier is operated at a 60 Hz line and has a filter capacitor connected across its output. What the value of capacitor is required if the load is 200Ω and the ripple must be no greater than 4%.

SOLUTION

$f_r = 2 \times 60 = 120$ HZ

$$C = \frac{1}{2\sqrt{3} f_r R_L r} = \frac{1}{2\sqrt{3}(120)(200)(0.04)} = 300.7\ \mu F$$

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EXAMPLE 12.3

A full wave rectifier is operated at 30 Hz, 120 V_{rms} line. It has a 100µF capacitor and a load 1KΩ

1- What is the percent ripple ?

2- What is the average current in R_L ?

SOLUTION

$f_r = 2 \times 30 = 60$ HZ

1- $r = \dfrac{1}{2\sqrt{3} f_r R_L C} \times 100 = \dfrac{1}{2\sqrt{3(60)(10^{-3})(10^{-4})}} \times 100 = 4.8\%$

2- $V_m = \sqrt{2}(120) = 169V$

$$V_{dc} = \frac{V_m}{1 + \dfrac{1}{2 f_r R_L C}} = \frac{169.7}{1 + \dfrac{1}{2(60)(10^3)(10^{-4})}} = 156.65V$$

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{156.65}{1000} = 156.65mA$$

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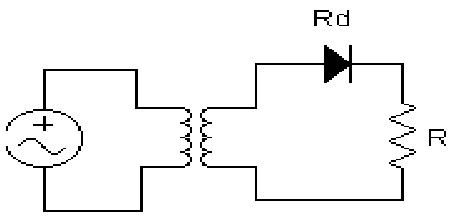
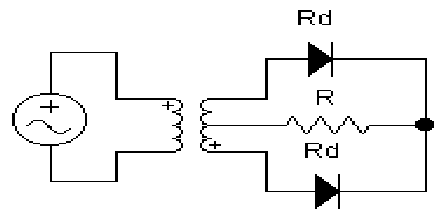
H.W.R



F.W.R



The Peak Inverse Voltage (PIV).

H.W.R: P.I.V $= V_m$

F.W.R: P.I.V $= 2V_m$

P.I.V $= V_m$ (for bridge)

❖ **The average (DC) voltage.**

$$V_{av} = V_{dc} = \frac{V_m}{\pi} = I_{dc} \cdot R \qquad V_{av} = V_{dc} = \frac{2V_m}{\pi} = I_{dc} \cdot R$$

❖ **The Root Mean Square (RMS) voltage.**

$$V_{r.m.s} = \frac{V_m}{2} \qquad V_{r.m.s} = \frac{V_m}{\sqrt{2}}$$

❖ **The average (DC) current .**

$$I_{av} = I_{dc} = \frac{I_m}{\pi} \qquad I_{av} = I_{dc} = \frac{2_{I_m}}{\pi}$$

❖ **The Root Mean Square (RMS) current.**

$$I_{r.m.s} = \frac{I_m}{2} = \frac{V_m}{2(R_d + R)} \qquad I_{r.m.s} = \frac{I_m}{\sqrt{2}} = \frac{V_m}{2(R_d + R)}$$

❖ **The Root Mean Square (RMS) Ripple voltage.**

$$V_{r\,(rms)} = 0.385V_m \qquad V_{r\,(rms)} = 0.308V_m$$

❖ **The Root Mean Square (RMS) Ripple current.**

$$I_{r\,(rms)} = 0.385I_m \qquad I_{r\,(rms)} = 0.308I_m$$

❖ **The DC power which reach to the load (R).**

$$P_{dc} = I^2_{dc}\, R = \left(\frac{I_m}{\pi}\right)^2 R \qquad P_{dc} = I^2_{dc}\, R = \left(\frac{2I_m}{\pi}\right)^2 R$$

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❖ **The AC power which enter to the rectifier.**

$P_{ac} = I_{r.m.s}^{2}(R_d + R)$ $\quad\quad$ $P_{ac} = I_{r.m.s}^{2}(R_d + R)$

$P_{ac} = I_{r.m.s}^{2}(2R_d + R)$ (for bridge)

❖ **The efficiency which define he ratio of the DC power which reach to the load (R) to the AC power which enter to the rectifier.**

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(I_{dc})^2 R}{(I_{rms})^2 (R_d + R)} = \frac{40.6}{1+\frac{R_d}{R}}$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{81.2}{1+\frac{R_d}{R}} = \frac{(I_{dc})^2 R}{(I_{rms})^2 (R_d + R)}$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{81.2}{1+\frac{2R_d}{R}} = \frac{(I_{dc})^2 R}{(I_{rms})^2 (2R_d + R)}$$

$\eta \cong 40.6\%$ $\quad\quad$ $\eta = \frac{P_{dc}}{P_{ac}} = \frac{81.2}{1+\frac{R_d}{R}}\% \cong 81.2\%$ (for bridge)

❖ **The maximum voltage.**

$(V_m)_R = I_m R$ $\quad\quad$ $(V_m)_R = I_m R$

❖ **The active power entered to rectifier which it the same dissipater power in diode and load.**

$P = I_{r.m.s}^{2} R_d$ $\quad\quad$ $P = I_{r.m.s}^{2} R_d$

❖ **The Ripple factor.**

$r = \frac{V_{r(rms)}}{V_{dc}} = 121\% = \frac{0.385V_m}{0.318V_m}$ $\quad\quad$ $r = \frac{V_{r(rms)}}{V_{dc}} = \frac{0.308V_m}{0.636V_m} = 48\%$

❖ **The voltage regulation define as the measurement to the ability of rectifier to keep the voltage on the load constant.**

$$V.R = \frac{V_{NL} - V_{FL}}{V_{FL}}$$

❖ **The no load voltage.**

$V_{N.L} = V_{dc}$

The full load voltage.

$V_{F.L} = V_{dc} - I_{d.c} \cdot R_d$

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EXAMPLE 12.5

A (200sin 100πt) volt apply to a H.W.R and the Resistor of diode ($R_d = 1000\Omega$) and the load Resistor ($R = 10^4\Omega$) calculate :

1- The max. current of cct.
2- The value of average current
3- The root mean square of current
4- The I/P power to regulator
5- The d.c O/P power
6- The ripple factor

SOLUTION

1- $I_m = \dfrac{V_m}{R_d + R} = \dfrac{200}{10^3 + 10^4} = 18.18mA$

2- $I_{dc} = \dfrac{I_m}{\pi} = \dfrac{18.18}{\pi} = 5.78mA$

3- $I_{r.m.s} = \dfrac{I_m}{2} = \dfrac{18.18}{2} = 9.09mA$

4- $P_{ac} = (I_{r.m.s})^2\,(R_d + R) = (9.09*10^{-3})^2\,(10^3 + 10^4) = 0.909$ W

5- $p_{dc} = I_{dc}^2\,R = (5.78*10^{-3})^2 *10^4 = 0.334$ W

6- $r = \dfrac{V_{r.rms}}{V_{d.c}} = \dfrac{0.355V_m}{0.318V_m} = 1.21 = 121\%$

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EXAMPLE 12.6

H.W.R connected to a supply of 220V and freq. 50 HZ through a transformer of rise ratio (1:2). Calculate the P.I.V and the O/P average voltage . assuming the losses voltage in diode is neglected . If we assume the losses voltage in diode is 15V when the current is maximum. Calculated the ratio of transform to the transformer when the O/P voltage is the same of case one .

SOLUTION

Part 1

$$\frac{V1}{V2} = \frac{N1}{N2} = \frac{I2}{I1}$$

$V_{secondray} = V_{primary} *2$

$= 220 * 2 = 440$ V

$V_m = \sqrt{2}\ V_{r.m.s}$

$= \sqrt{2}\ (440) = 622$ V

$V_{d.c} = V_{av} = \frac{V_m}{\pi} = \frac{622}{\pi} = 198$ V

Part 2

$V_{m1} = V_m + V_{\text{losses diode}}$

$V_{m1} = 622+15 = 637$ V

$V_{av} = V_{dc} = \frac{V_m}{\sqrt{2}} = \frac{637}{\sqrt{2}} = 450$ V

$$\frac{N2}{N1} = \frac{V2}{V1}$$

$$= \frac{450}{220} = 2.04$$

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EXAMPLE 12.7

Transformer of 117V for a primary coil and (275-0-275) for a secondary coil provide a load of 10 kΩ by a F.W.R. calculate each of V_L and I_L and the I/P current for the rectifier and the I/P power for the transformer .

SOLUTION

$$V_{dc} = \frac{2V_m}{\pi}$$

$$V_m = \sqrt{2}V_{rms} = \sqrt{2} \times 275 \text{ volt}$$

$$1\text{-}V_{dc} = \frac{2(275\sqrt{2})}{\pi} = 247 \text{ volt}$$

$$2\text{-}I_{dc} = \frac{V_{dc}}{R} = \frac{247}{10 \times 10^3} = 0.0247 \text{ Amp} = 24.7 \text{ mA}$$

$$3\text{-}I_{r.m.s} = \frac{V_{r.m.s}}{R} = \frac{275}{10 \times 10^3} = 27.5mA$$

$$4\text{-}p_{in} = I_{r.m.s} \cdot V_{r.m.s}$$

$$\frac{N2}{N1} = \frac{I1}{I2}$$

$$I_1 = I_2 * \frac{N2}{N1}$$

$$I_1 = 27.5*10^{-3} \left(\frac{275}{117}\right) = 64.63 \text{ mA}$$

$$p_{in} = (64.63*10^{-3})*(117) = 7.56 \text{ W}$$

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