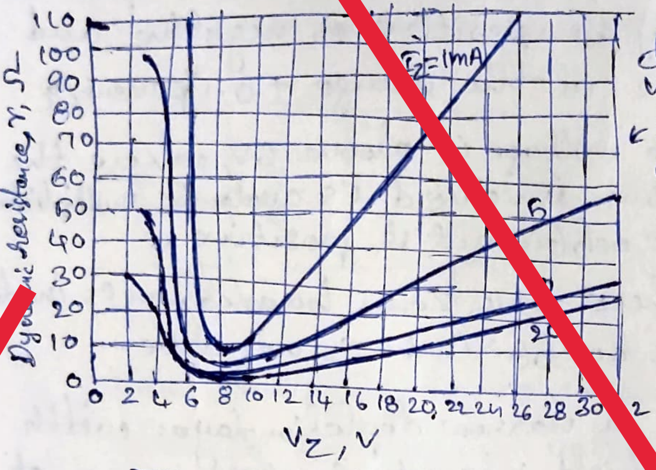
→ Therefore the value of avalanche voltage must increase upon increased temperature.

→ Dynamic Resistance and Capacitance

→ For a Zener diode, if the reciprocal slope $\Delta V_Z/\Delta I_Z$, called dynamic resistance, is r, then a change ΔI_Z in the operating current of the diode produces a change $\Delta V_Z = r\Delta I_Z$ in the operating voltage.

→ Ideally, r = 0, corresponding to a volt-ampere curve which, in the breakdown region, is precisely vertical.



Dynamic resistance at a number of currents for Zener diodes of different Operating voltages at 25°C

→ The broader minimum occurs in the range 6 to 10V, and at large V_Z and small I_Z, the dynamic resistance r may become quite large.

→ The capacitance across a breakdown diode is the transition capacitance and hence varies inversly as some power of voltage.

→ Since C_T is proportional to cross-sectional area of the diode, high-power avalanche diodes have very large capacitances.

→ Values of C_T from 10 to 10,000 pF are common.

P-N Junction as a Rectifier

→ One of the important applications of the diode is the rectifier circuits.

→ These circuits are used to convert the ac i/p of the normal available power supply into a dc o/p.

→ The dc source of power is an important requirement in almost all electronic systems like televisions, stereos and computers.

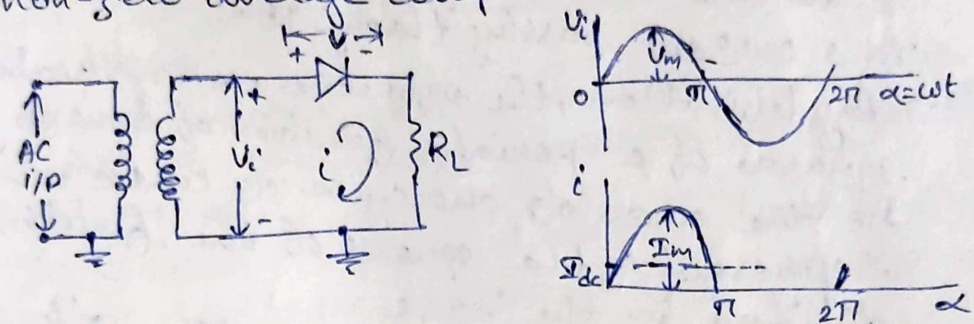
→ However, the o/p of a rectifier circuit always contains some ac components.

→ Filtering techniques are employed to remove the harmonic ac components from the rectifier o/p to obtain a more accurate dc o/p.

A Half-Wave Rectifier

→ Any electrical device which offers a low resistance to current in one direction but a high resistance to current in opposite direction is called a rectifier.

→ Such a device is capable of converting a sinusoidal i/p waveform, whose average value is zero, into a unidirectional (though not const.) waveform, with a non-zero average component



→ The rectifying device is usually a semiconductor diode (or for very high voltages, a vaccum-tube diode)

→ From the piecewise linear approximation for the diode the device has essentially infinite resistance in the reverse direction (for $V < V_\gamma$) and a small and constant resistance R_f in the forward direction (for $V > V_\gamma$)

→ Since in the rectifier circuit, the i/p $V_i = V_m \sin\omega t$ has a peak value V_m which is very large compared with the offset voltage V_γ

→ We assume $V_\gamma = 0$. Subject to this idealization of the diode characteristic, the current in the diode or load R_L is given by

$$i = I_m \sin\alpha \quad \text{where } 0 \le \alpha \le \pi$$

$$i = 0 \quad \text{where } \pi \le \alpha \le 2\pi$$

$$\text{where } \alpha = \omega t, \quad I_m = \frac{V_m}{R_f + R_L}$$

→ The o/p current is unidirectional and has a non-zero average value.

→ **Reading of a dc Ammeter**

→ A dc ammeter is constructed so that the needle deflection indicates the average value of the current passing through it.

→ By definition, the average value of a periodic function is given by the area of one cycle of the curve divided by the base

→ Mathematically $I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i\, d\alpha$

→ For half-wave circuit

$$I_{dc} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\alpha\, d\alpha = \frac{I_m}{\pi}$$

→ Reading of an ac Ammeter

→ An ac ammeter is constructed so that the needle deflection indicates the effective or rms current passing through it.

→ By definition, the effective or rms value squared of a periodic function of time is given be the area of one cycle of curve which represents the square of the function, divided by the base

→ Mathematically $I_{rms} = \left(\frac{1}{2\pi}\int_0^{2\pi} i^2\, d\alpha\right)^{1/2}$

→ For half-wave circuit

$$I_{rms} = \left(\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\alpha\, d\alpha\right)^{1/2}$$

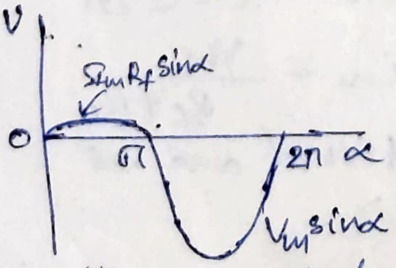
$$= \frac{I_m}{2}$$

→ The rms value of a sinusoidal wave is $\frac{I_m}{\sqrt{2}}$

→ Reading of a dc Voltmeter

→ This instrument reads the average value of the voltage across its terminals.

→ If the voltmeter is across diode, the instantaneous diode voltage must be plotted, and the area under one cycle of the curve must be found.



Voltage across diode in half wave rectifier

→ When diode is conducting, it has a resistance R_f, and voltage across it is iR_f

→ When diode is non-conducting, the current is zero, and the transformer secondary voltage V_i appears across the diode.

→ Thus

$$V = iR_f = I_m R_f \sin\alpha, \quad 0 \le \alpha \le \pi$$

$$V = V_m \sin\alpha, \quad \pi \le \alpha \le 2\pi$$

→ The reading of the dc voltmeter is

$$V_{dc} = \frac{1}{2\pi}\left(\int_0^{\pi} I_m R_f \sin\alpha \, d\alpha + \int_{\pi}^{2\pi} V_m \sin\alpha \, d\alpha\right)$$

$$= \frac{1}{\pi}(I_m R_f - V_m) = \frac{1}{\pi}[I_m R_f - I_m(R_f + R_L)]$$

$$V_{dc} = -\frac{I_m R_L}{\pi}$$

→ This result is negative, which means that if the voltmeter is to read upscale, its positive terminal must be connected to cathode of the diode.

→ The voltmeter reading does not equal the product of the direct current I_{dc} times the diode resistance R_f

→ The reason is that diode is a non-linear device whose resistance is constant (and equals R_f) only when the anode voltage is positive.

→ The dc voltage across the load does equal the product of direct current I_{dc} times the output resistance R_L because the load is a truly const. resistor.

→ Reading of a Wattmeter

→ This instrument is built to indicate the average value of the product of the instantaneous current through its current coil and the instantaneous voltage across its potential coil.

→ Hence the power read by a wattmeter, whose voltage coil is placed across the transformer secondary, is

$$P_i = \frac{1}{2\pi}\int_0^{2\pi} v_i \, i \, d\alpha$$

Since $v_i = i(R_f + R_L)$ for $0 \le \alpha \le \pi$

$$P_i = \frac{1}{2\pi}\int_0^{2\pi} i^2 (R_f + R_L) \, d\alpha$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\alpha \, (R_f + R_L) \, d\alpha$$

$$P_i = I_{rms}^2 (R_f + R_L)$$

→ Peak Inverse Voltage

→ For each rectifier circuit there is a max. voltage to which the diode is subjected.

- → This potential is called peak inverse voltage, because it occurs during that part of the cycle when the diode is non-conducting.
- → For the half-wave ckt (without a filter) the peak inverse voltage is V_m, the peak transformer secondary voltage.

Regulation

- → The variation of dc o/p voltage as a function of dc load current is called regulation.
- → The percentage regulation is defined as

$$\% \text{ regulation} = \frac{V_{\text{no load}} - V_{\text{full load}}}{V_{\text{full load}}} \times 100\%$$

- → For an ideal power supply, the o/p voltage is independent of the load (the o/p current) & the regulation is zero
- → The variation of V_{dc} with I_{dc} for half-wave rectifier is obtained as follows;

$$I_{dc} = \frac{I_m}{\pi} = \frac{V_m/\pi}{R_f+R_L}$$

$$V_{dc} = I_{dc}R_L = I_{dc}(R_f+R_L) - I_{dc}R_f$$

$$= \frac{I_m(R_f+R_L)}{\pi} - I_{dc}R_f = \frac{V_m}{\pi} - I_{dc}R_f$$

- → This result shows that V_{dc} equals $\frac{V_m}{\pi}$ at no load and the dc voltage decreases linearly with an increase in dc o/p current.
- → The larger the magnitude of the diode forward resistance, the greater is this decrease for a given current change.
- → The effective internal resistance of the power supply is R_f
- → In practice, the resistance R_s of the transformer secondary is in series with the diode and R_s should be added to R_f in $V_{dc} = \frac{V_m}{\pi} - I_{dc}R_f$
- → Consider a 12V 100 mA supply with $R_f+R_s=20\Omega$ The no-load voltage is 12 V, the full load voltage is $12-(0.1)(20)=10V$, the percentage regulation is $\frac{12-10}{10} \times 100 = 20\%$.

→ Power-supply Specifications

→ The most important characteristics which must be specified for a power supply are the following:

1) The required o/p dc voltage
2) The regulation
3) The average and peak currents in each diode
4) The peak inverse voltage of each diode
5) The ripple factor

→ Ripple Factor

→ The purpose of a rectifier is to convert alternating into direct current.

→ In the conversion from an alternating current into a unidirectional current, periodically fluctuating components still remaining in the o/p wave

→ It is for this reason that filters are frequently used in order to decrease these ac components.

→ A measure of the fluctuating components is given by the ripple factor r, which is defined as

$$r \equiv \frac{\text{rms value of alternating components of wave}}{\text{average value of wave}}$$

$$r \equiv \frac{I'_{rms}}{I_{dc}} \equiv \frac{V'_{rms}}{V_{dc}} \quad — ①$$

where the terms I'_{rms} and V'_{rms} denote the rms value of ac components of current and voltage respectively.

→ By noting the instantaneous ac component of current is given by $i' = i - I_{dc}$

then $$I'_{rms} \equiv \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(i')^2\,d\alpha}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(i - I_{dc})^2\,d\alpha}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(i^2 - 2iI_{dc} + I_{dc}^2)\,d\alpha}$$

→ The ripple current $$= \sqrt{I_{rms}^2 - 2I_{dc}^2 + I_{dc}^2} \quad \left(\because \frac{1}{2\pi}\int_0^{2\pi} i\,d\alpha = I_{dc}\right)$$

$$I_{rms} = \sqrt{I_{rms}^2 - I_{dc}^2} \quad — ②$$

→ Combining ① & ② $$r = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

$$r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

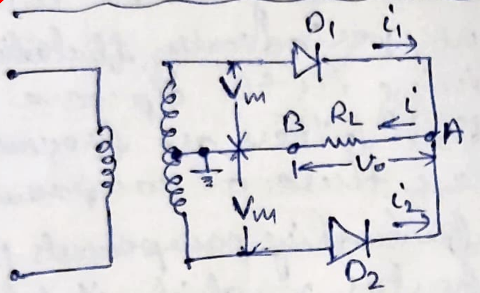
→ For the half-wave rectifier, the ratio

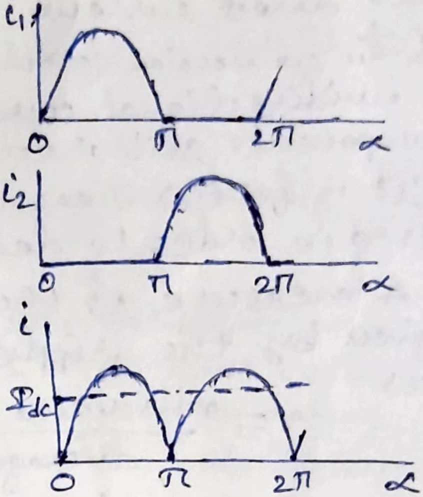
$$\frac{I_{rms}}{I_{dc}} = \frac{I_m/2}{I_m/\pi} = \frac{\pi}{2} = 1.57$$

Hence $r = \sqrt{(1.57)^2 - 1} = 1.21$

→ This result indicates that the rms ripple voltage exceeds the dc o/p voltage & shows that the half-wave rectifier is a relatively poor ckt for converting alternating into direct current.

Full-Wave Rectifier





→ The ckt of a full-wave rectifier comprise two half-wave ckts which are so connected that conduction take place through one diode during one half of the power cyle & through the other diode during the second half of the power cycle.

→ The current to the load is the sum of these two currents.

→ The dc and rms values of the load current in such a system from the definitions are found to be

$$I_{dc} = \frac{2I_m}{\pi}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

where $I_m = \frac{V_m}{R_f + R_L}$

and V_m is the peak transformer secondary voltage from an end to the center tap.

→ The direct current supplied to the load for full wave connection is twice that for the half-wave ckt

→ The i/p power supplied to the ckt in full-wave case is given by same expression as for half-wave case

$$P_i = I_{rms}^2 (R_f + R_L)$$

→ Ripple Factor

↳ The required current ratio that appears in expression for ripple factor is

$$\frac{I_{rms}}{I_{dc}} = \frac{I_m/\sqrt{2}}{2I_m/\pi} = 1.11$$

→ The ripple factor for full-wave ckt is

$$\gamma = \sqrt{(1.11)^2 - 1} = 0.482$$

→ Regulation

↳ The dc o/p voltage is given by $V_{dc} = \frac{2V_m}{\pi} - I_{dc}R_f$

→ Peak Inverse Voltage

↳ At the instant of time when transformer secondary voltage to midpoint is at its peak value V_m, diode D_1 is conducting and D_2 is non-conducting

→ If we apply KVL around the outside loop and neglect the small voltage drop across D_1, we obtain $2V_m$ for the peak inverse voltage across D_2.

→ This result is obtained without reference to the nature of the load, which can be a pure resistance R_L or a combination of R_L and some reactive elements which may be introduced to filter the ripple.

→ So in a full-wave ckt, independently of the filter used, the peak inverse voltage across each diode is twice the maximum voltage measured from midpoint to either end.

~~→ Bridge Rectifier~~

~~↳ The full-wave rectifier ckt requires a center-tapped transformer where only one half of the total ac voltage of transformer secondary winding is utilized to convert into dc o/p.~~

~~→ Now we consider a different configuration of the full-wave ckt, called bridge rectifier, where the entire ac voltage of transformer secondary is used to convert into the dc voltage.~~