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Rectification :-

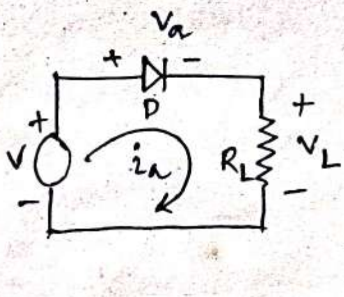
The process by which an alternating current (or voltage) is transformed into a direct current (or voltage) is called rectification.

⇒ An electrical device having a low resistance to current in one direction and a relatively high resistance to current in the reverse direction serves as a rectifier.

Dynamic characteristic of a diode

→ Let a diode D be connected to the source of voltage v through a load resistance R_L. Due to the flow of the diode current i_a a voltage drop $v_L = i_a R_L$ appears across R_L. If v_a is the voltage drop across the diode, we have by KVL

$$v_a = v - v_L = v - i_a R_L \quad \text{--- (1)}$$



→ The static characteristic of the diode gives the variation of i_a with v_a. The dynamic characteristic of the diode which we shall immediately obtain, gives the variation of i_a with the supply voltage v.

→ Equation (1) shows that the plot of i_a against v_a is a straight line through the points ($i_a = 0$, $v_a = v$) and ($i_a = v/R_L$, $v_a = 0$).

→ Thus the intercept of the straight line on the voltage axis is v and than on the current axis is v/R_L. The slope of the straight line, called the load line, is $-1/R_L$. [study from book].

Half-wave Rectifier

→ Since the negative half cycles of the input voltage are cut off and are absent from the output load voltage in the circuit which uses a single diode, the circuit is refferred to as a half-wave rectifier.

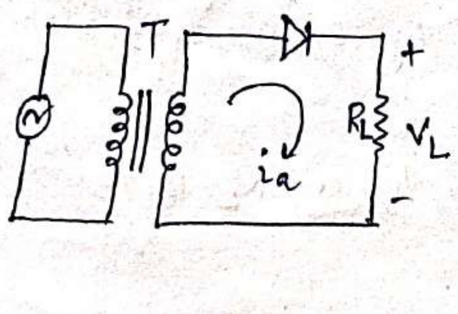
→ A practical half-wave rectifier circuit, shown in fig, uses a transformer T at the input.

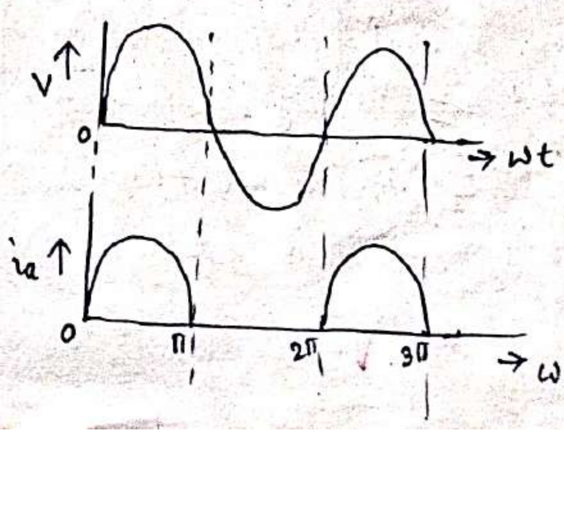
→ The purpose of the transformer is to step up or step down the ac mains voltage connected to its primary.

→ If the ac mains voltage is $E_p \sin \omega t$, the rectifier input voltage is $e = E_s \sin \omega t = n E_p \sin \omega t$, where n is the transformer secondary-to-primary turns ratio, and E_p is the amplitude of the ac mains voltage.

→ By adjusting n, the secondary voltage is made to suit the diode rating.

→ The diode current i_a flows during the positive half cycles of the input voltage, as shown in Fig.





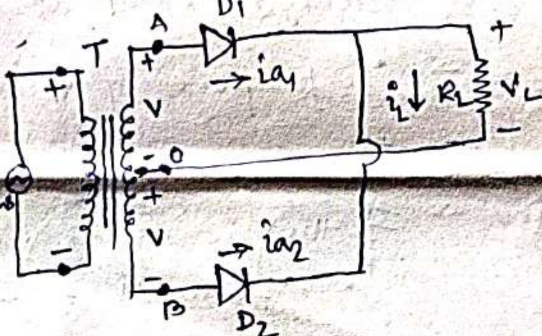
Full wave ~~recfi~~ rectifier

→ If two diodes are so connected that conduction occurs through one diode during one half of the input voltage cycle and through the other diode during the ~~x~~ next half of the cycle, a unidirectional current can flow through the load resistance during the full cycle of the input voltage. Such a circuit is called a full-wave rectifier.

→ This is an improvement over a half-wave rectifier where the output current flows only for the positive half cycles of the input voltage.

→ A full-wave rectifier circuit is shown in fig.

→ T is a centre-tapped transformer, and D_1 and D_2 are two identical diodes.



→ As each half of the transformer secondary has equal number of turns, the volltage induced in each half of the secondary is equal in magnitude but opposite in phase.

→ Let at any instant of the input half cycle, the point A have a positive voltage with respect to the centre point O. The point B has an equal magnitude of negative voltage with respect to O. So, the diode D_1 conducts and D_2 does not during this half cycle.

→ In the following half cycle, D_2 conducts and D_2 remains off.

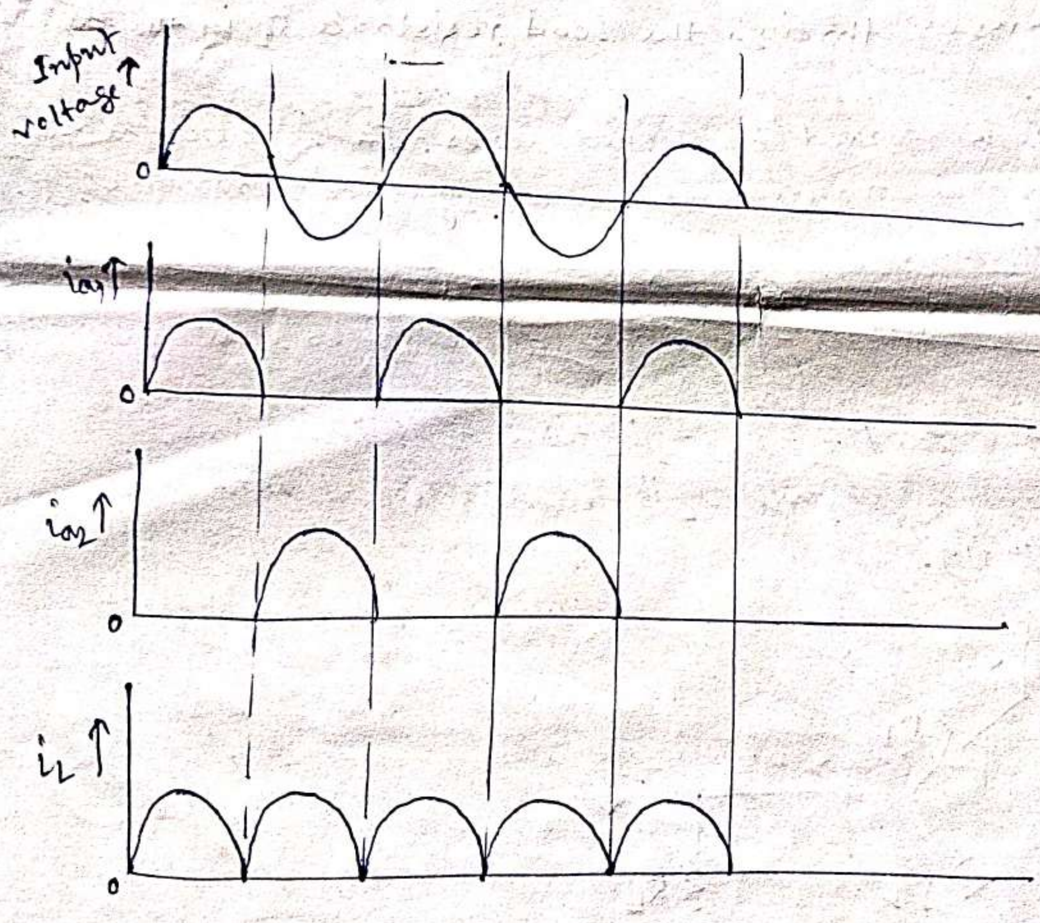
→ The diode currents i_{a_1} and i_{a_2} carried by D_1 and D_2 respectively, are depicted ~~by~~ in fig.

→ The current i_L through the load resistance R_L is the sum of i_{a_1} and i_{a_2}, and is exhibited in fig.

- The load current i_L is thus unidirectional in each half cycle and is shared alternately by the two diodes.

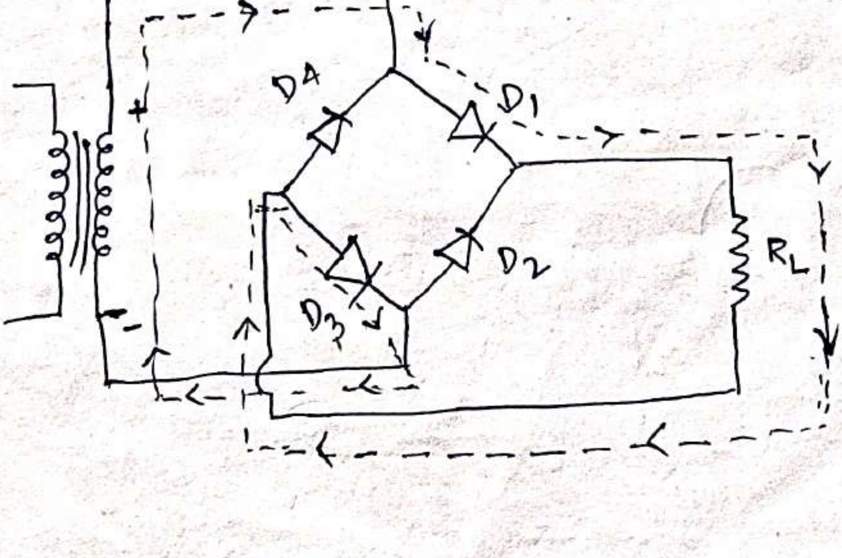
→ The output voltage $v_L (= i_L R_L)$ has the same waveform as the load current i_L.

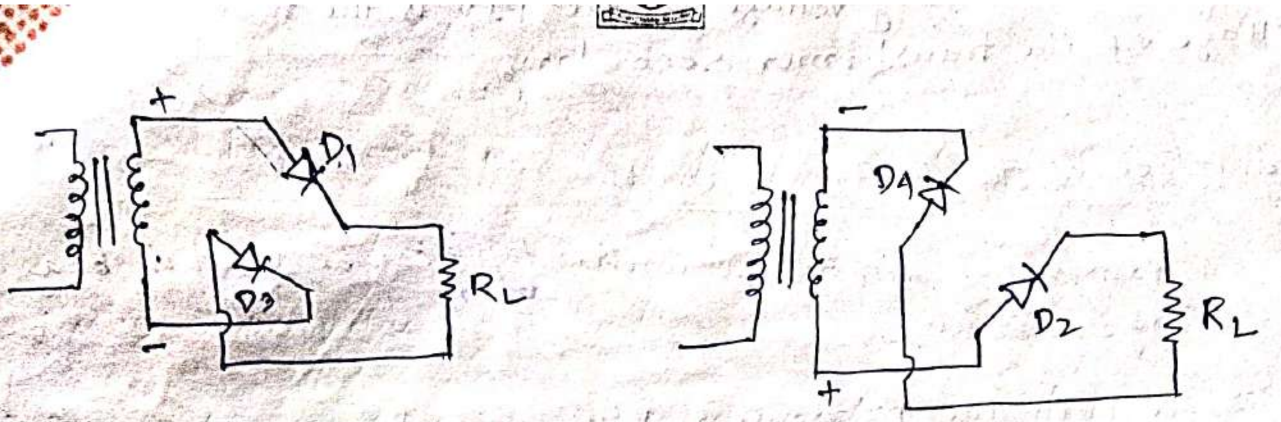
→ Since the diodes D_1 and D_2 are identical, the average value of i_L of a full-wave rectifier is double that of a half-wave rectifier using a similar diode.



Bridge Rectifier

- → Full wave rectification is also achieved with the aid of a bridge circuit employing four diodes.
- → In the circuit, only two diodes in the opposite arms of the bridge conduct simultaneously while the other two diodes remain off.
- → For the instantaneous polarity of the transformer secondary voltage shown in fig, the diodes D_1 and D_3 conduct, but the diodes D_2 and D_4 do not.
- → A current i thus passes through the load resistance R_L in the direction of the arrowhead.
- → The conduction path is marked by dashed lines. In the next half cycle, the polarity of the transformer secondary voltage reverses.
- → Now D_2 and D_4 conduct, and D_1 and D_3 are off.
- → But the load current flows in the same direction as that preceding half cycle.
- → For the full cycle, the load current is thus unidirectional. Consequently, the output voltage v_L is unidirectional with the polarity as marked in fig.





Peak Inverse Voltage:-

→ The peak inverse voltage (abbreviated PIV) is the maximum reverse voltage to which the diode is subjected when it is nonconducting.

→ The rated PIV is specified by the diode manufacturer.

→ The maximum rated PIV of a silicon diode is greater than that of a Ge diode.

→ To avoid a possible damage, the diode must not be subjected to a PIV exceeding its rated value.

→ In a half-wave rectifier, the PIV is the maximum voltage appearing across the transformer secondary.

→ Neglecting the small voltage drop across the conducting diode in a full wave rectifier, the PIV for each diode is found to be twice the maximum voltage between the centre tap and either end of the secondary of the tranformer.

→ In bridge circuit, each nonconducting diode is subjected to the transformer secondary voltage; so the PIV is the maximum voltage of the transformer secondary.

Advantage of the bridge rectifier

1. A transformer without a centre tap can be used in a bridge circuit.

2. Since both the primary and the secondary currents in the transformer are sinusoidal, the bridge circuit required a smaller transformer than that needed by a full-wave rectifier giving the same dc output voltage.

3. The PIV rating of a diode in a ~~brig~~ bridge rectifier is half that for a full wave circuit yielding the same dc output voltage.

Disadvantage of bridge rectifier

1. A full-wave rectifier uses two diodes whereas a bridge rectifier employs four diodes.

2. Since the current flows through two diodes in series in a bridge circuit a large power is dissipated in the diodes. Hence, the bridge circuit is not efficient for low voltages.

Factors determining rectifier performance

a/ Average or DC value of the load current

→ The load current of a rectifier is unidirectional but fluctuating.

→ Since it is a periodic function of time, by Fourier's theorem, it can be thought to have an average value superimposed on which are sinusoidal currents having harmonically related frequencies.

→ The average or the dc value of the load current is

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t)$$

Here, i_L is the instantaneous load current at time t and ω is the angular frequency of the input sinusoidal voltage.

b/ Ripple Factor

→ Periodically fluctuating components – the ripples – are superimposed on I_{dc} to give the actual load current.

→ Due to these fluctuating components, the conversion of ac to dc by a rectifier is not perfect.

→ The ripple factor, denoted by γ, gives a measure of of this imperfection or of the fluctuating components.

→ The ripple factor is defined by

$$\gamma = \frac{\text{rms value of the alternating components of the load currents (or}}{\text{average value of the load current (or voltage)}}$$

$$= \frac{I'_{rms}}{I_{dc}} = \frac{V'_{rms}}{V_{dc}}$$

where, I'_{rms} and V'_{rms} are, respectively, the rms values of the alternating components of the load current and the load voltage. V_{dc} is the average or the dc load voltage. If R_L is the load resistance, we obtain, $V_{dc} = I_{dc} R_L$ and $V'_{rms} = I'_{rms} R_L$

The instantaneous ac component of the load current is

$$i' = i_L - I_{dc}$$

i_L → is the instantaneous total load current.

The rms value of the ~~alter~~ alternating component of the load current (or the ripple current) is

$$I'_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} (i_L - I_{dc})^2 \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{1}{2\pi}\int_0^{2\pi} (i_L^2 - 2 i_L I_{dc} + I_{dc}^2) \, d(\omega t)\right]^{1/2}$$

If I_{rms} is the rms or the effective value of the total load current, we have

$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} i_L^2 \, d(\omega t)$$

$$I'_{rms} = (I_{rms}^2 - 2I_{dc}^2 + I_{dc}^2)^{1/2}$$

$$= (I_{rms}^2 - I_{dc}^2)^{1/2}.$$

$$\left[I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t). \right.$$

$$\gamma = \frac{(I_{rms}^2 - I_{dc}^2)^{1/2}}{I_{dc}} = \frac{(V_{rms}^2 - V_{dc}^2)^{1/2}}{V_{dc}}.$$

Where, $V_{rms} (= R_L I_{rms})$ denotes the rms value of the total load voltage. A small value of γ is desirable for good rectification.

Rectification Efficiency

→ The efficiency of rectification is defined to the ratio of the dc output power (P_{dc}) to the ac input power (P_i) of the rectifier.

It is denoted by η and is usually expressed as a percentage. Thus

$$\eta = \frac{P_{dc}}{P_i} \times 100 \text{ percent}.$$

The quantity η is also referred to as the theoretical efficiency or the conversion efficiency of the rectifier.

We have
$$P_{dc} = I_{dc}^2 R_L$$

and
$$P_i = \frac{1}{2\pi} \int_0^{2\pi} v \cdot i_L \, d(\omega t)$$

where v is the instantaneous input voltage at time t. If R_f is the forward resistance of the diode, KVL gives

$$v = i_L (R_f + R_L)$$

If R_f is assumed to be a constant,

$$P_i = \frac{R_f + R_L}{2\pi} \int_0^{2\pi} i_L^2 \, d(\omega t)$$

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

Therefore, $$\eta = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_f + R_L)} \times 100$$

$$= \left(\frac{I_{dc}}{I_{rms}}\right)^2 \cdot \frac{1}{1 + R_f/R_L} \times 100 \text{ percent.}$$

η has a high value for a good rectifier.

I_{dc}, γ and η for a half-wave rectifier

In the half-wave rectifier circuit, the load current is given by

$i_L = I_m \sin \omega t$, if $0 \le \omega t \le \pi$

and, $= 0$ if $\pi \le \omega t \le 2\pi$

where I_m is the amplitude or the peak value of the diode current. If V_s is the amplitude of the transformer secondary voltage, we have

$$I_m = \frac{V_s}{R_f + R_L}$$

The effective resistance of the transformer secondary, if not negligible, will have to be added to $(R_f + R_L)$.

So, $$I_{dc} = \frac{1}{2\pi} \int_0^{2\pi} i_L \, d(\omega t)$$

$$= \frac{1}{2\pi} \int_0^{\pi} I_m \sin \omega t \, d(\omega t) = \frac{I_m}{\pi}$$

The upper limit of the integral is π instead of 2π since $i_L = 0$ in the interval from π to 2π.

We obtain

$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2 \omega t \; d(\omega t) = \frac{I_m^2}{4}$$

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

Therefore, $\frac{I_{rms}}{I_{dc}} = \pi/2 = 1.57$.

and, $\gamma = \left[\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1\right]^{1/2} = 1.21$.

and

$$\eta = \left(\frac{2}{\pi}\right)^2 \frac{1}{1 + R_f/R_L} \times 100 \text{ percent}$$

$$= \frac{40.6}{1 + R_f/R_L} \text{ percent}.$$

I_{dc}, γ and η for a full-wave rectifier

$$I_{dc} = \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin \omega t \; d(\omega t) + \int_{\pi}^{2\pi} (-I_m \sin \omega t \; d(\omega t))\right] = \frac{2I_m}{\pi}$$

where, $I_m = \frac{V_s}{R_f + R_L}$ with V_s as the maximum voltage between the centre tap and either end of the transformer secondary.

$$I_{rms} = \left[\frac{1}{2\pi}\left[\int_0^{\pi} I_m^2 \sin^2 \omega t \, d(\omega t) + \int_{\pi}^{2\pi} I_m^2 \sin^2 \omega t \, d(\omega t)\right]\right]$$

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

Thus, $\frac{I_{rms}}{I_{dc}} = \frac{\pi}{2\sqrt{2}} = 1.11$

The ripple factor is $\gamma = \left[(1.11)^2 - 1\right]^{1/2} = 0.482$

and the conversion efficiency is

$$\eta = \frac{81.2}{1 + R_f/R_L} \text{ per cent.}$$

→ We find that I_{dc} and η of a full-wave rectifier are two times those of a half-wave rectifier.

→ Also, the ripple factor of a full-wave rectifier is smaller by a factor of 2.5 than that for a half-wave circuit.

→ Therefore, a full-wave circuit performs better than a half-wave rectifier.

→ If a bridge rectifier is used, R_f is replaced by $2R_f$, since two diodes in series conduct simultaneously.

→ The ripple factor for a bridge rectifier is 0.482, the same as that for a full-wave rectifier.

Regulation

$$I_{dc} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t \, d(\omega t) = \frac{I_m}{\pi}$$ for half-wave rectifier.

$$I_{dc} = \frac{2}{2\pi}\int_0^{\pi} I_m \sin\omega t \, d(\omega t) = \frac{2I_m}{\pi}$$ for Full-wave rectifier.

and $$I_m = \frac{V_s}{R_f + R_L}$$

From the above eqn's, we infer that the average load current can, in general, be written as

$$I_{dc} = K I_m = \frac{K V_s}{nR_f + R_L}$$

where $K = \frac{1}{\pi}$ for a half wave rectifier and $K = 2/\pi$ for a full-wave rectifier or bridge rectifier.

$n = 1$ for half-wave and full wave rectifier, and $n = 2$ for a bridge rectifier. The dc load voltage is

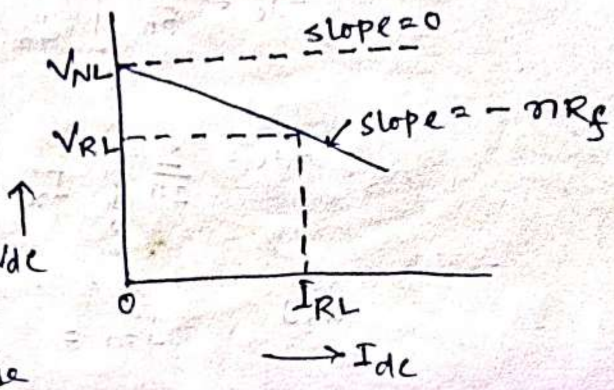
$$V_{dc} = I_{dc} R_L = KV_s - I_{dc} \cdot nR_f$$

A plot of V_{dc} against I_{dc} given in Fig, shows that V_{dc} decreases linearly with increasing I_{dc}. The slope of the straight line is $-nR_f$ and its intercept on the V_{dc} axis is KV_s which is the open-circuit or no-load output voltage, denoted by V_{NL}.

→ In practice, the resistance R_s of the transformer secondary should be added to nR_f since it is in series with the diode.

→ The diode resistance can be experimentally determined from the plot given in fig.

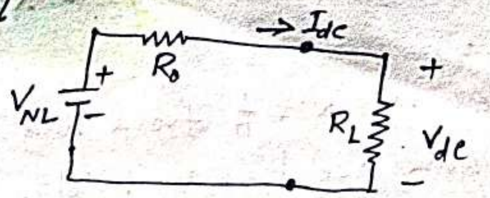
→ The output voltage V_{RL} for a normal or rated load current I_{RL} is less than V_{NL} by an amount increasing with the diode resistance.



→ For an ideal diode $R_f = 0$ whence the slope of the V_{dc} versus I_{dc} straight line is zero.

→ The thevenin equivalent circuit of a rectifier is depicted in fig. This equivalent circuit follows from eqⁿ.

$$V_{dc} = I_{dc}R_L = KV_S - I_{dc}nR_f$$



→ The rectifier behaves as a voltage source having a generated voltage V_{NL} and an internal resistance (the output resistance) R_0.

→ For a full-wave or a half wave rectifier $R_0 = R_f$. and for a bridge rectifier $R_0 = 2R_f$.

→ The variation of V_{dc} with I_{dc} is called regulation, and the plot of V_{dc} versus I_{dc} is referred to as the voltage regulation characteristic of the rectifier.

→ In the ideal rectifier, V_{dc} is independent of I_{dc} so that the voltage regulation characteristic is parallel to the I_{dc} axis.

→ In practice, the departure of the behaviour of an actual rectifier from that of an ideal rectifier is expressed by percentage voltage regulation.

It is defined as

$$\text{Percentage voltage regulation} = \frac{V_{NL} - V_{RL}}{V_{RL}} \times 100\,\%$$

$$= \frac{I_{dc}\, n R_f}{I_{dc}\, R_L} \times 100\,\%$$

$$= \frac{n R_f}{R_L} \times 100\,\%$$

→ In the ideal situation, the percentage regulation is zero.

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TUR (Transformer Utilization Factor)

→ This is defined as the ratio of the power delivered to the load (P_{dc}) and ac rating of the transformer secondary ($P_{ac(rated)}$)

$$TUR = \frac{P_{dc}}{P_{ac(rated)}}$$

Now, $P_{dc} = I_{dc}^2 R_L$

and $P_{ac} = V_{rms} \times I_{rms}$.

For a half-wave rectifier, the rated secondary voltage is

$V_{rms} = \frac{V_m}{\sqrt{2}}$, $I_{rms} = \frac{I_m}{2}$ and $I_{dc} = \frac{I_m}{\pi}$

$$\left[\begin{array}{l} V_{rms} = I_{rms} \cdot R_L = \frac{V_m}{} \\ I_{rms} = \frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2 \omega t \, d(\omega t) \\ I_d = \frac{1}{2\pi}\int_0^{\pi} I_m \sin \omega t \, d(\omega t). \end{array}\right.$$

∴ for half wave rectifier $TUF = \frac{\left(I_m/\pi\right)^2 \cdot R_L}{\left(\frac{V_m}{\sqrt{2}}\right)\left(I_m/2\right)}$

$$= \frac{\left(\frac{I_m}{\pi}\right)^2 \cdot R_L}{I_m^2 \frac{(R_f + R_L)}{(2\sqrt{2})}} \qquad \left[\because I_m = \frac{V_m}{R_f + R_L}\right]$$

$$= \frac{2\sqrt{2}}{\pi^2} \cdot \frac{1}{1 + \left(\frac{R_f}{R_L}\right)}$$

for a diode circuit usually, $R_f \ll R_L$, then $TUF = \frac{2\sqrt{2}}{\pi^2} = 0.287$.

→ For a full-wave rectifier average TUF is found out by considering primary and secondary windings separately. In a centre-tap rectifier the dc currents in the two halves of the transformer secondary flow in opposite directions.

$$\text{TUF of primary} = \frac{I_{dc}^2 R_L}{V_{rms} I_{rms}} = \frac{\left(\frac{2I_m}{\pi}\right)^2 \cdot R_L}{\frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}}$$

using $I_{dc} = \frac{2I_m}{\pi}$, $I_{rms} = \frac{I_m}{\sqrt{2}}$, $V_{rms} = \frac{V_m}{\sqrt{2}}$

$$\therefore \text{TUF (of primary)} = \frac{8}{\pi^2} \times \frac{R_L}{R_f + R_L}$$

for $R_f << R_L$

$$\text{TUF for primary} = \frac{8}{\pi^2} = 0.812$$

Now, TUF for secondary $= 2 \times$ TUF of half-wave

$= 2 \times 0.286$

$= 0.572$

[As transformer secondary for centre-tap can be consider as equivalent to two half-wave rectifier circuit.]

$$\therefore (\text{TUF})_{av} = \frac{0.812 + 0.572}{2} = 0.692.$$

→ For bridge rectifier the current flow through both of primary and secondary are sinusoidal and there is no centre-tap at secondary. Hence TUF for both primary and secondary are 0.812 and average TUF is 0.812.