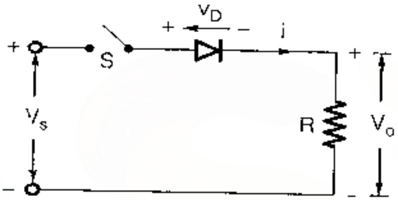
Diode Circuits and Rectifiers

3

Diode circuits with DC source

(a) Resistive Load

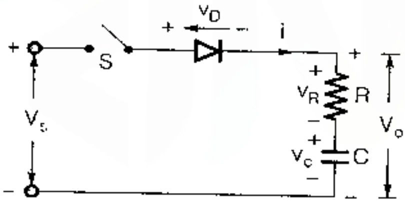


- Load current

$$i(t) = \frac{V_s}{R}$$

where, V_s = D.C. source voltage
R = Load resistance

(b) RC Load



- Load current

$$i(t) = \frac{V_s}{R} e^{-t/RC}$$

- Voltage across capacitor

$$v_c(t) = V_s(1 - e^{-t/RC})$$

where, $v_c(t)$ = Voltage across capacitor at time t

- Initial rate of rise of capacitor voltage

$$\left(\frac{dV_c}{dt}\right)_{t=0} = \frac{V_S}{RC}$$

- Time constant

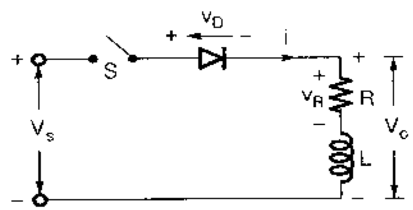
$$\tau = RC = \frac{\text{Source voltage } (V_s)}{\left(\frac{dv_c}{dt}\right)_{t=0}}$$

Remember: ....

At $t = 0$, capacitor acts as a conductor and at $t \to \infty$, it acts as an insulato

....

(c) RL load



- Load current

$$i(t) = \frac{V_s}{R}\left(1 - e^{-\frac{R}{L}t}\right)$$

- Voltage across inductor

$$v_L(t) = V_s \cdot e^{-\frac{R}{L}t}$$

- Initial rate of rise of current

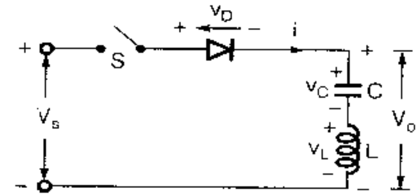
$$\left(\frac{di}{dt}\right)_{t=0} = \frac{V_s}{L}$$

Remember: ....

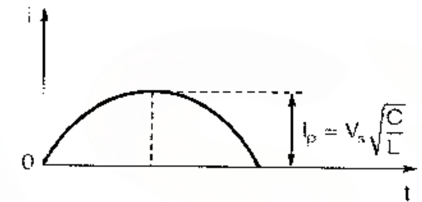
At $t = 0$, inductor acts as an insulator and at $t \to \infty$, it acts as a conducto

....

(d) LC load



- Load current

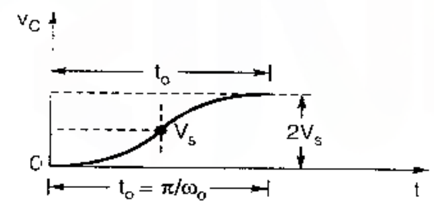


$$i(t) = V_s\sqrt{\frac{C}{L}} \sin \omega_0 t$$

where, ω_0 = Resonant frequency of the circuit

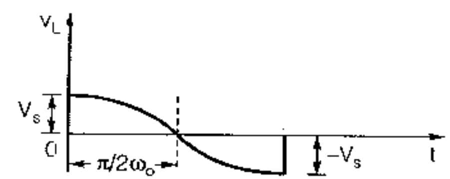
$$\omega_0 = \frac{1}{\sqrt{LC}}$$

- Voltage across capacitor



$$v_C(t) = V_s(1 - \cos \omega_0 t)$$

- Voltage across inductor



$$v_L(t) = V_s \cos \omega_0 t$$

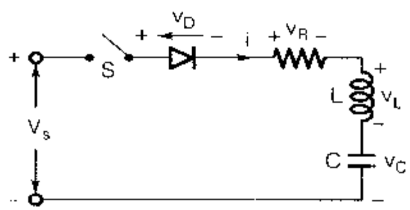
- Conduction time

$$t_0 = \frac{\pi}{\omega_0} = \pi\sqrt{LC}$$

Remember:

- If we provide D.C. voltage to LC parameter, the current will be alternating in nature.
- In LC circuit when current follow sine curve, voltage follow cosine curve. This characteristic is used in commutation technique.

(e) RLC load



- Characteristic equation

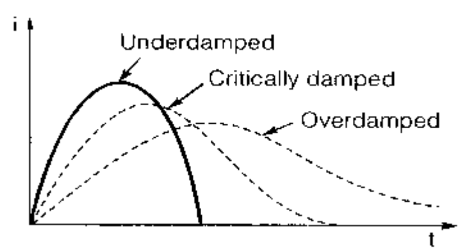
$$s^2 + \frac{R}{L}s + \frac{1}{LC} = 0$$

- Damping factor

$$\alpha = \frac{R}{2L} = \xi\omega_o$$

- Ringing frequency

$$\omega_r = \sqrt{\omega_0^2 - \alpha^2} \text{ in rad/sec}$$



Case 1. $\alpha < \omega_0$

- Roots of characteristic equation are complex.
- Circuit is under damped.

$$i(t) = \frac{V_s}{\omega_r L} \cdot e^{-\alpha t} \sin\omega_r t$$

Case 2. $\alpha > \omega_0$

- Roots are real.
- Circuit is overdamped.

$$i(t) = \frac{V_s}{L\sqrt{\alpha^2 - \omega_0^2}} \cdot \sinh\left(\sqrt{\alpha^2 - \omega_0^2}\,t\right)$$

Case 3. $\alpha = \omega_0$

- Roots are equal.
- Circuit is critically damped.

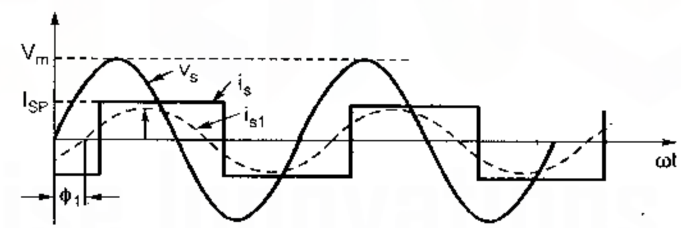
$$i(t) = \frac{V_S}{L} \cdot t e^{-\alpha t}$$

Performance Parameters

If V_S = RMS value of supply phase voltage

I_S = RMS value of supply phase current including fundamental and harmonics

I_{S1} = RMS value of fundamental component of supply current I_S



- Input power factor

$$P.F. = \frac{\text{Mean ac input power}}{\text{Total rms input voltamperes}}$$

$$P.F. = \frac{I_{S1}}{I_S}\cos\phi_1$$

- RMS value of harmonic components

$$I_h = \sqrt{I_S^2 - I_{S1}^2}$$

- Input current harmonic factor (HF)

$$HF = \frac{I_h}{I_{S1}} \quad \text{or} \quad HF = \sqrt{\frac{I_S^2 - I_{S_1}^2}{I_{S_1}^2}}$$

- Crest factor (CF)

$$CF = \frac{I_{SP}}{I_S}$$

where, I_{SP} = Peak input current

- Form factor (FF)

$$FF = \frac{V_{or}}{V_o}$$

where V_{or} = RMS value of output voltage
V_o = Average value of output voltage

- Displacement factor (DF) = $\cos\phi_1$
- Ripple voltage (V_r)

$$V_r = \sqrt{V_{or}^2 - V_o^2}$$

- Voltage ripple factor (VRF)

$$VRF = \frac{V_r}{V_o}$$

- Transformer utilization factor (TUF)

$$TUF = \frac{P_{dc}}{V_s I_s}$$

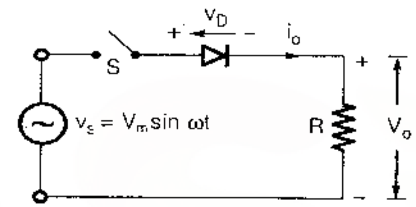
where, V_S = RMS voltage of the secondary winding of transformer
I_S = RMS current of the secondary winding of transformer
$P_{dc} = V_o I_o$ = DC output power
V_o = Average output voltage
I_o = Average output current

Diode Rectifiers

A rectifier employing diode is called an uncontrolled rectifier, because its average output voltage is a fixed D.C. voltage.

1. Single Phase Half-Wave Diode Rectifier

(a) Resistive Load:



- Voltage rms value of output

$$V_{or} = \frac{V_m}{2}$$

where, V_m = Maximum value of source voltage (v_S)

- Average value of output voltage

$$V_o = \frac{V_m}{\pi}$$

- Power delivered

P = (RMS load voltage) (RMS load current)

$$P = I_{or}^2 R$$

where, I_{or} = RMS value of load current

- Peak inverse voltage (PIV) = V_m
- Input power factor

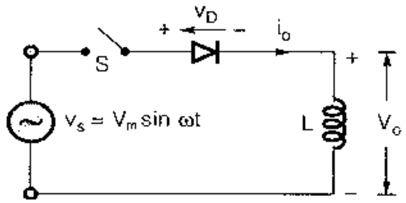
$$\text{Input p.f.} = \frac{\text{Power delivered to load}}{\text{Input VA}}$$

$$\text{Input p.f.} = \frac{V_{or} \cdot I_{or}}{V_s \cdot I_{or}} = 0.707$$

Remember:

Peak inverse voltage (PIV) is the maximum voltage that appears across the device during its blocking state.

(b) Inductive Load:



- Output current

$$i_o = \frac{V_m}{\omega L}(1 - \cos \omega t)$$

- Peak value of current

$$I_{max} = \frac{2V_m}{\omega L}$$

- Average value of current

$$I_o = \frac{1}{2} I_{max}$$

- RMS value of fundamental current

$$I_{1r} = \frac{I_o}{\sqrt{2}}$$

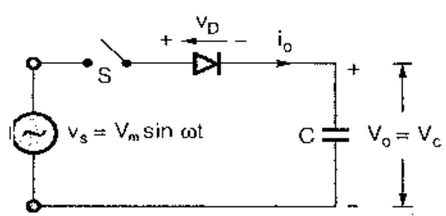
- Output voltage

$$v_o = V_m \sin \omega t = v_s$$

- Average value of output voltage

$$V_o = 0$$

(c) Capacitive Load



- Output current

$$i_o = \omega C V_m \cos \omega t$$

- Output voltage

$$v_o = V_m \sin \omega t = v_s = v_c$$

- Diode voltage

$$v_D = V_m(\sin \omega t - 1)$$

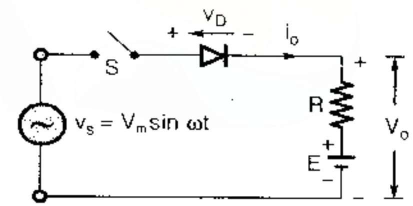
- Average value of Diode voltage

$$V_D = V_m$$

- RMS value of diode voltage

$$V_{rD} = 1.225\ V_m$$

(d) RE Load



- Turn-on angle

$$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$$

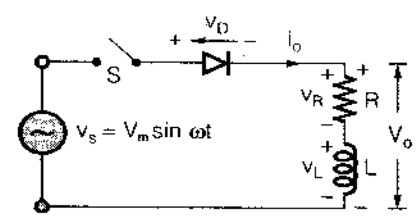
- Average value of output current

$$I_o = \frac{1}{2\pi R}\left[2V_m \cos \theta_1 - E(\pi - 2\theta_1)\right]$$

Note:

- Conduction angle for diode $= \pi - 2\theta_1$
- PIV for diode $= V_m + E$

(e) RL Load



- Average value of output voltage

$$V_o = \frac{V_m}{2\pi}(1 - \cos\beta)$$

where, β = Extinction angle of the diode

- Average value of output current

$$I_o = \frac{V_m}{2\pi R}(1 - \cos\beta) \quad \text{For } 0 \le \omega t \le \beta$$

2. Single phase full wave diode rectifier

- Average output voltage

$$V_o = \frac{2V_m}{\pi}$$

- RMS value of output voltage

$$V_{or} = \frac{V_m}{\sqrt{2}}$$

Comparison of various 1-ϕ diode rectifier

Parameters	Half-wave	Full-wave	
		Centre-tap (M-2)	Bridge (B-2)
DC output voltage, V_o	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
RMS output voltage, V_{or}	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$
Ripple voltage, V_r	$0.3856\ V_m$	$0.3077\ V_m$	$0.3077\ V_m$
Voltage ripple factor, VRF	1.211	0.482	0.482
Rectifier efficiency, η	40.53%	81.06%	81.06%
TUF	0.2865	0.672	0.8106
PIV	V_m	$2V_m$	V_m
Crest factor, CF	2	$\sqrt{2}$	$\sqrt{2}$
Number of diodes	1	2	4
Ripple frequency	f	2f	2f

3. Three-phase half-wave diode rectifier

R Load

- Average value of output voltage

$$V_o = \frac{3\sqrt{6}}{2\pi}V_{ph} = \frac{3}{2\pi}\cdot V_{ml}$$

where, V_{mp} = Maximum value of phase voltage, V_{ph}

V_{ml} = Maximum value of line voltage, V_l

$V_l = \sqrt{3}\cdot V_{ph}$

Comparison of Various 3-ϕ Diode Rectifier

Parameters	3-Pulse Rectifier	6-Pulse Rectifier M-6 Type	6-Pulse Rectifier B-6 Type	12-Pulse Rectifier
DC output voltage, V_o	$\frac{3V_{ml}}{2\pi}$	$\frac{3V_{mp}}{\pi}$ or $\frac{\sqrt{3}V_{ml}}{\pi}$	$\frac{3\sqrt{3}V_{mp}}{\pi}$ or $\frac{3V_{ml}}{\pi}$	$1.91\ V_{ml}$
RMS output voltage, V_{or}	$0.4854\ V_{ml}$	$0.55185\ V_{ml}$	$0.9558\ V_{ml}$	$1.9101\ V_{ml}$
Ripple voltage, V_r	$0.0872\ V_{ml}$	$0.02356\ V_{ml}$	$0.0408\ V_{ml}$	$0.019545\ V_{ml}$
Voltage ripple factor, VRF	0.1826 or 18.26%	0.043 or 4.3%	0.0427 or 4.27%	0.01023 or 1.023%
Rectifier efficiency, η	96.765%	99.82%	99.82%	–
TUF	0.6644	0.551	0.9541	–
PIV	V_{ml}	$1.155\ V_{ml}$	V_{ml}	–
Form factor, FF	1.0165	1.0009	1.0009	1.00005

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