Power Electronics circuits /Equipments

1.0 Classification

CONVERTER

AC → DC(Avg. value is finite)

INVERTER

DC → AC(Avg. value is zero)

CHOPPER (DRIVES)/ SMPS

DC → Variable DC

PHASE CONTROLLER

AC → [ ] → AC('F' is fixed. 'V' is variable)

CYCLO CONVERTER / MATRIX CONVERTER

AC → [ ] → AC ('F' & 'V' are variable)

2. Converter

__Assumptions:__ 1. All the devices and circuit components are ideal.

2. Input is a pure sine wave.

2.1 Diode Circuits

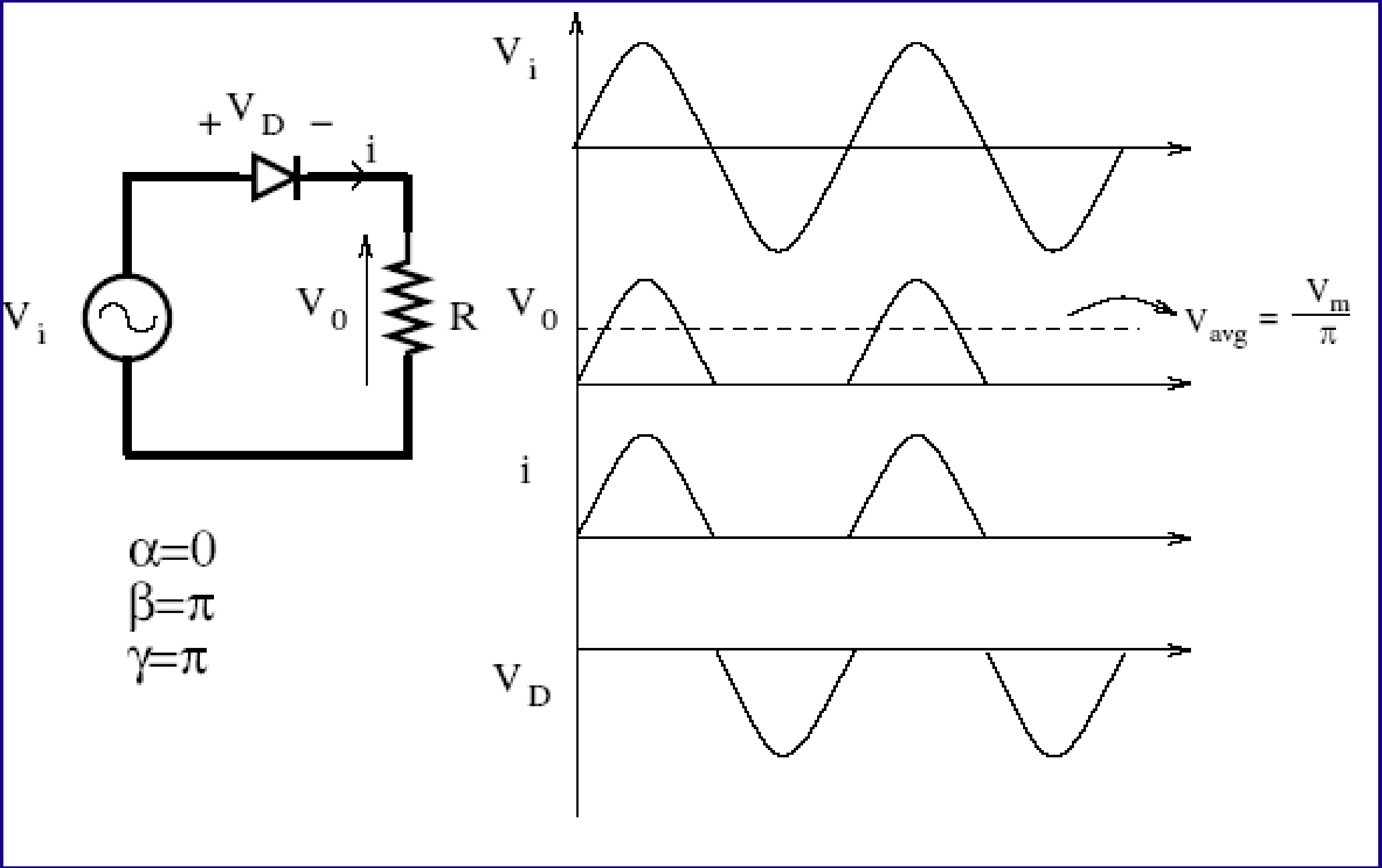
- Uncontrolled Rectification

Let α = the angle at which diode starts conducting.

β = the angle at which diode stops conducting.

γ = conduction angle = $\beta - \alpha$

2.1.1 Half Bridge: R-Load



$$V_i = V_m \sin \omega t = Ri = V_0$$

$$i = \frac{V_m}{R} \sin \omega t, \ i = I_{max} \ \text{at} \ \omega t = \pi/2$$

$$V_{avg} = V_m / \pi$$

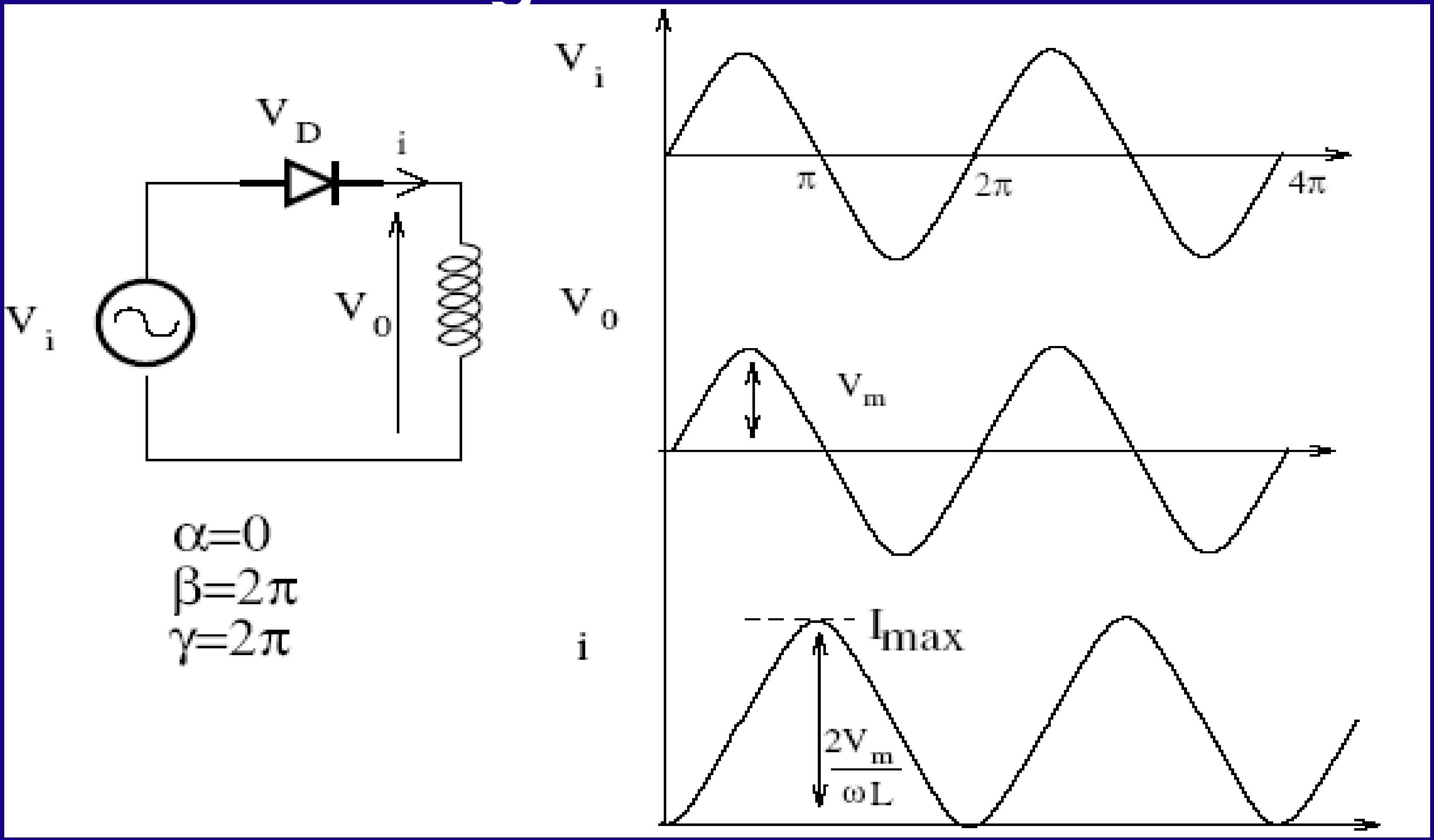
$$V_{rms} = V_m / 2$$

$$V_{ripple} = \sqrt{(V_{rms}^2 - V_0^2)}$$

$\rightarrow$ Measure of AC component in V_0

Ripple Factor $= V_{ripple} / V_0 = 1.21$

2.1.2 Half Bridge: L-Load



$$V_i = L\frac{di}{dt} = V_m \sin\omega t,\ i = I_{max} \text{ at } \omega t = \pi$$

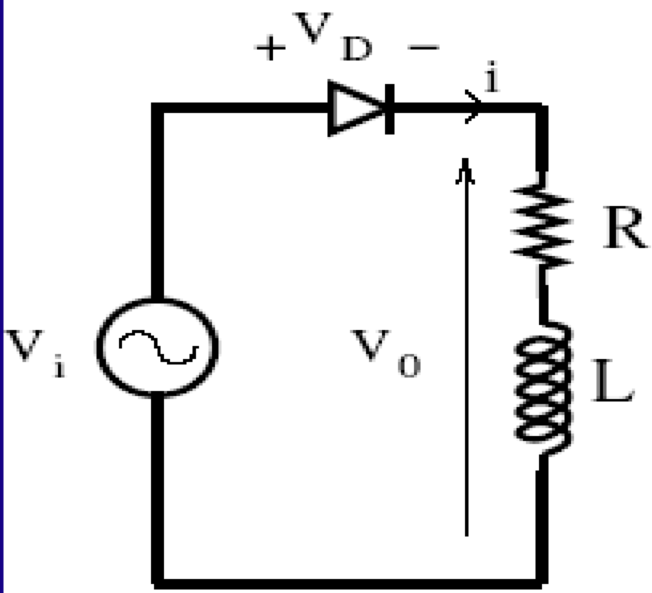
$$i = \frac{V_m}{\omega L}(1 - \cos\omega t)$$

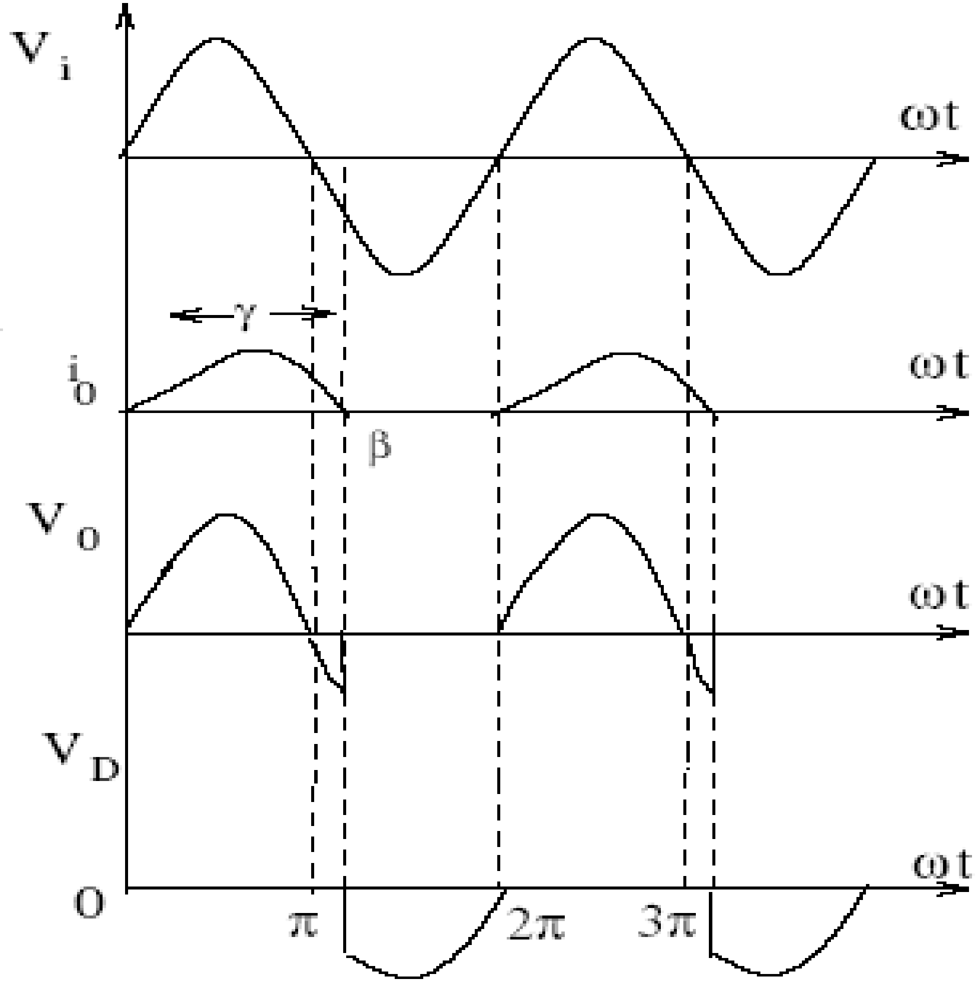
$$V_0 = V_i = V_m \sin\omega t$$

$$V_{avg} = 0$$

$$\text{Power delivered to load} = V_{avg} I_{avg} = 0$$

2.1.2 Half Bridge: R-L-Load





$$\mathrm{Ri} + \mathrm{L}\frac{\mathrm{di}}{\mathrm{dt}} = \mathrm{V_m} \sin \omega t$$

$$\mathrm{i} = \frac{\mathrm{V_m}}{\mathrm{Z}}[\sin(\omega t - \phi) + \mathrm{k_1} e^{-\frac{\mathrm{R}t}{\mathrm{L}}}]$$

$$\text{where } \mathrm{Z} = \sqrt{\mathrm{R}^2 + \omega L^2} \ \& \ \phi = \tan^{-1}\frac{\omega \mathrm{L}}{\mathrm{R}}$$

$$\text{At } \omega\mathrm{t} = 0 \text{ , } \mathrm{i} = 0$$

$$\therefore \ \mathrm{i} = \frac{\mathrm{V_m}}{\mathrm{Z}}[\sin(\omega t - \phi) + \sin(\phi) e^{-\frac{\mathrm{R}t}{\mathrm{L}}}] \quad 0 < \omega t < \beta$$

$$\mathrm{i} = \mathrm{i_{max}} \qquad \pi/2 < \omega t < \pi$$

$$\mathrm{V_0} = \mathrm{Ri_{max}}$$

$$\mathrm{V_{avg}} = \frac{\mathrm{V_m}}{2\pi}(1 - \cos\beta)$$

Observation:

- γ increases with increase in ‘L’.
- Avg. V_0 decreases with increase in ‘L’.

<u>What is the significance of γ ?</u>

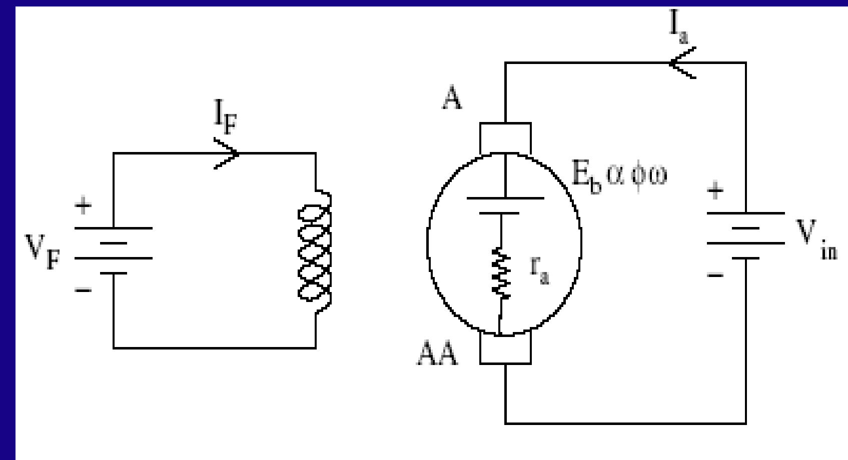
Or why should the current be continuous in the load ?

<u>Consider a DC motor driving a load</u>

Developed Torque = $kI_F I_a = T_e$

$$J\frac{d\omega}{dt} + B\omega + T_L = T_e$$

$$\frac{d\omega}{dt} = [T_e - T_L]/J$$



At Steady state $\frac{d\omega}{dt} = 0$

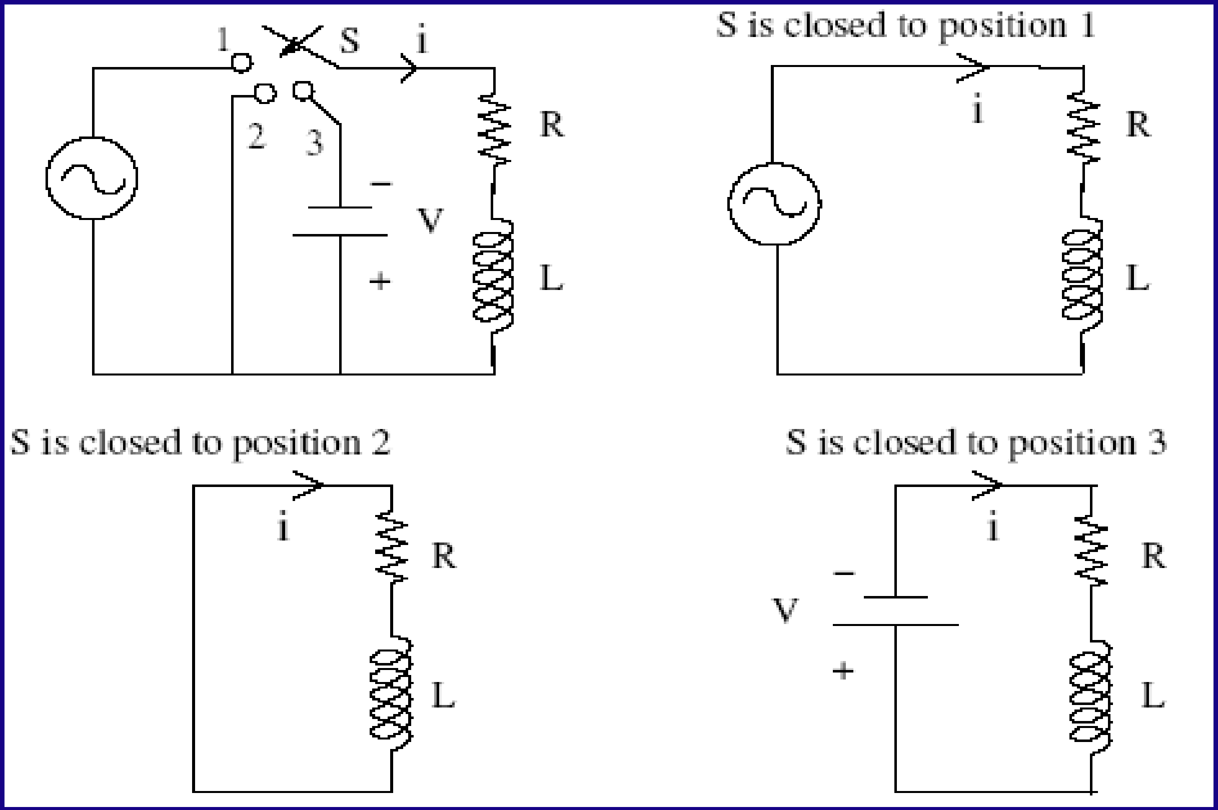
Possible only if T_e is constant $\Rightarrow$ if $\mathrm{I_a}$ and $\mathrm{I_F}$ are constant.

If $\mathrm{I_a} = 0,\ T_e = 0$

Speed will PULSATE

$\Rightarrow$ Always desirable to have finite $\mathrm{I_a}$ if not constant ‘ $\mathrm{I_a}$ ‘.

$\Rightarrow$ Just increasing ‘L’ is not a solution (γ increases with increasing ‘L’, but avg. $\mathrm{V_0}$ decreases.)



$$Ri + L\frac{di}{dt} = 0$$

i decays slowly

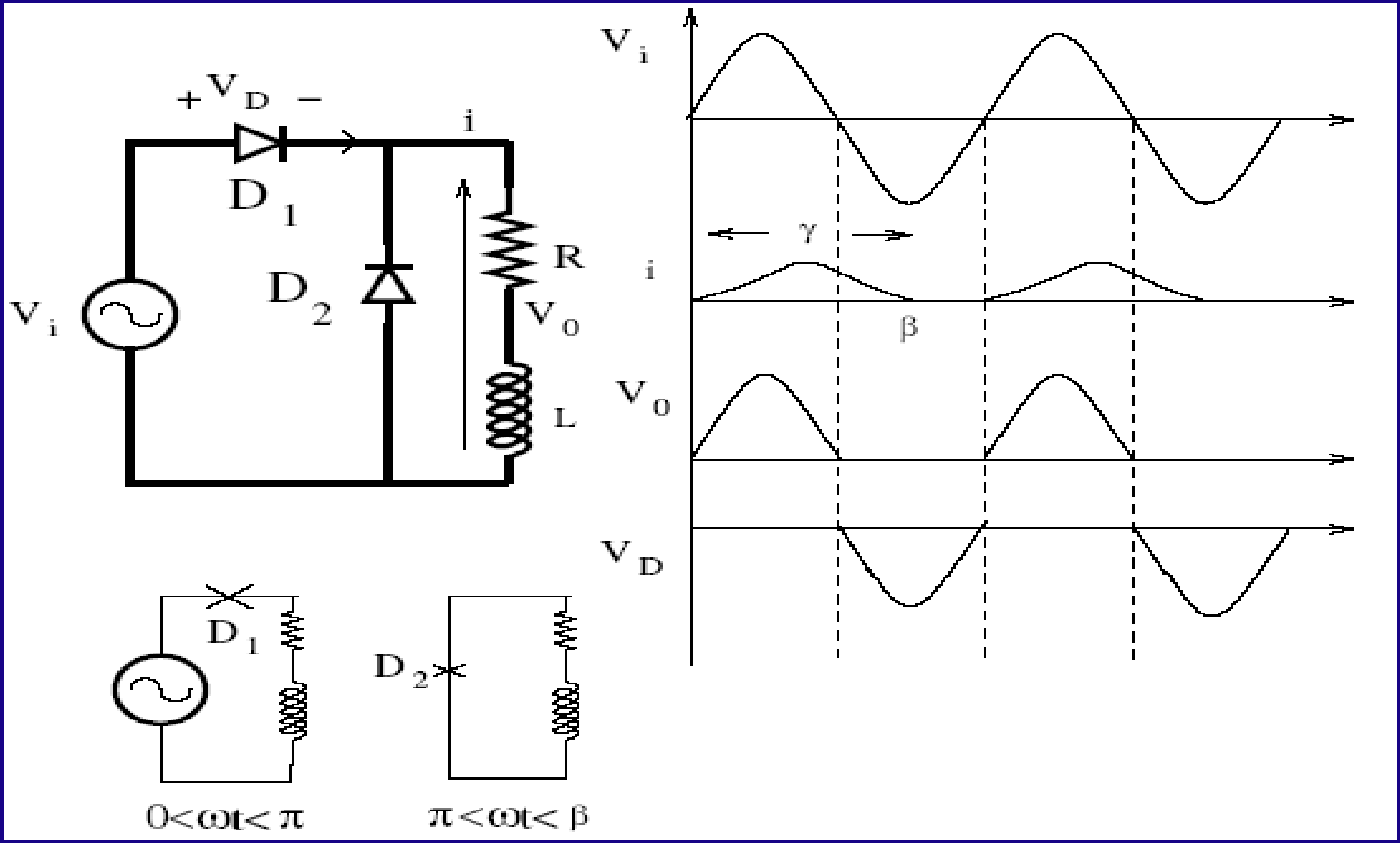
$V_0 =$ constant with $\uparrow \beta$

$$Ri + L\frac{di}{dt} = -V$$

i decays very fast

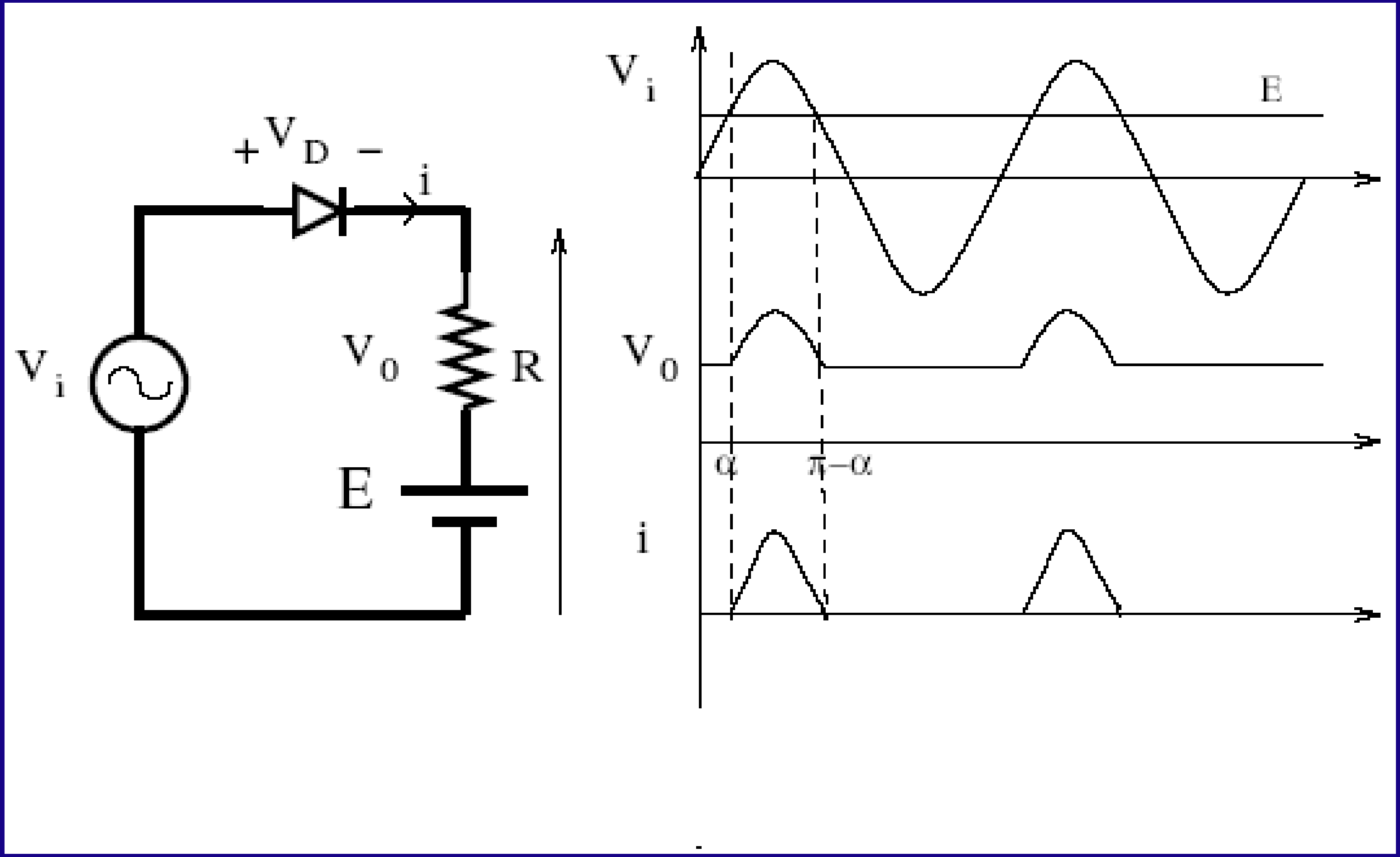
$V_0 \downarrow$ with $\uparrow \beta$

2.1.4 Freewheeling Diode



2.1.5 Load is R-L-E

- <u>Case – 1: L=0</u>



Diode can conduct when $V_m \sin \omega t = E$

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

When diode is ON, $V_0 = V_i$

When diode is OFF, $V_0 = E$

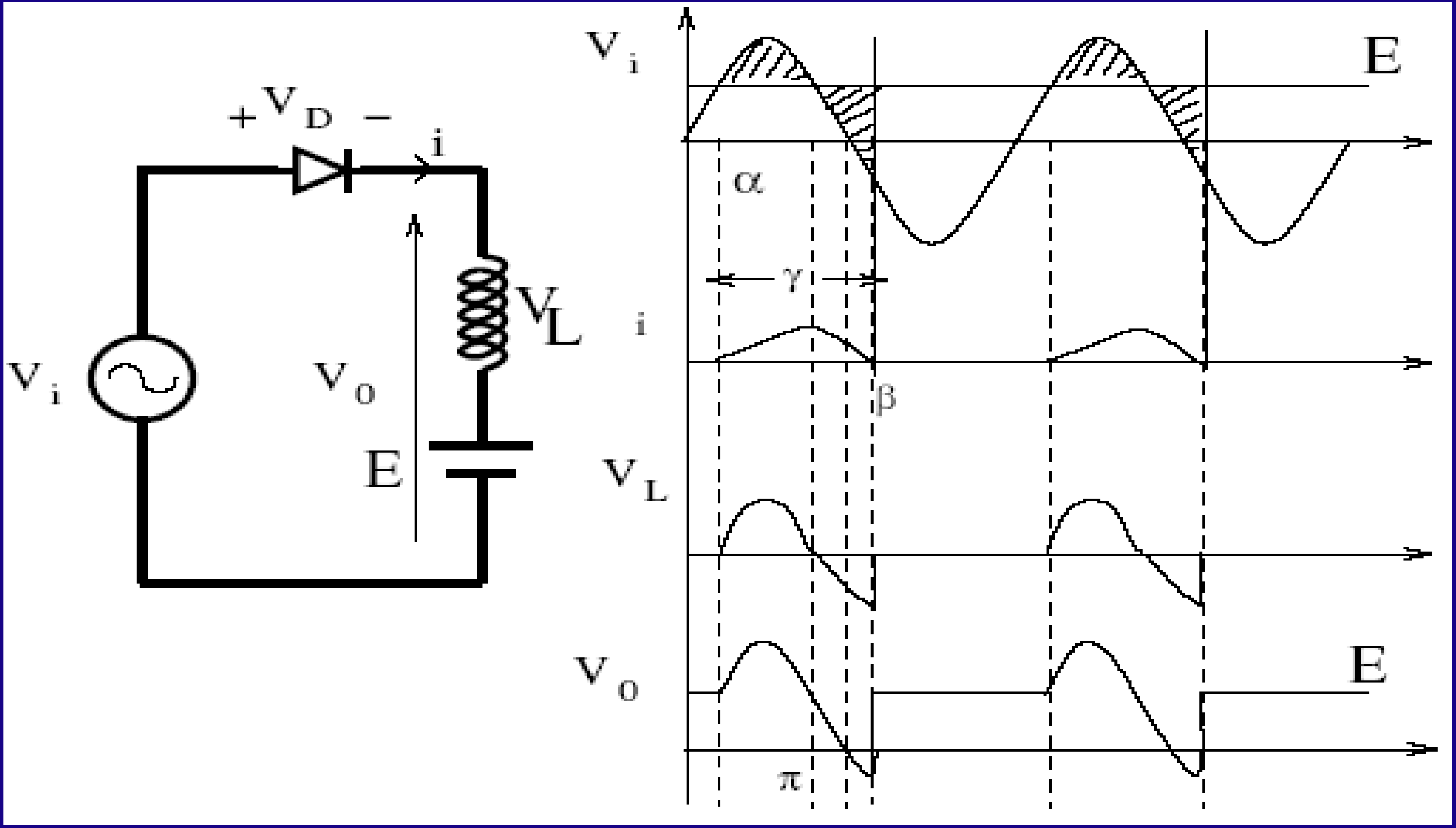
Applying KVL, $V_i = Ri + E$

$i = [V_m \sin \omega t - E]/R$

Diode turns off at $\beta = \pi - \alpha$

$i = I_{max}$ at $\omega t = \pi/2$

Case – 2: R=0



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

$$\text{when diode is ON, } V_i = L\frac{di}{dt} + E$$

$$\text{'i' starts } \uparrow \text{ beyond } \alpha$$

$$i = I_{max} \text{ at } \pi - \alpha$$

$$i = I_{max}, \frac{di}{dt} = 0$$

$$V_i = E \text{ at } \omega t = \pi - \alpha$$

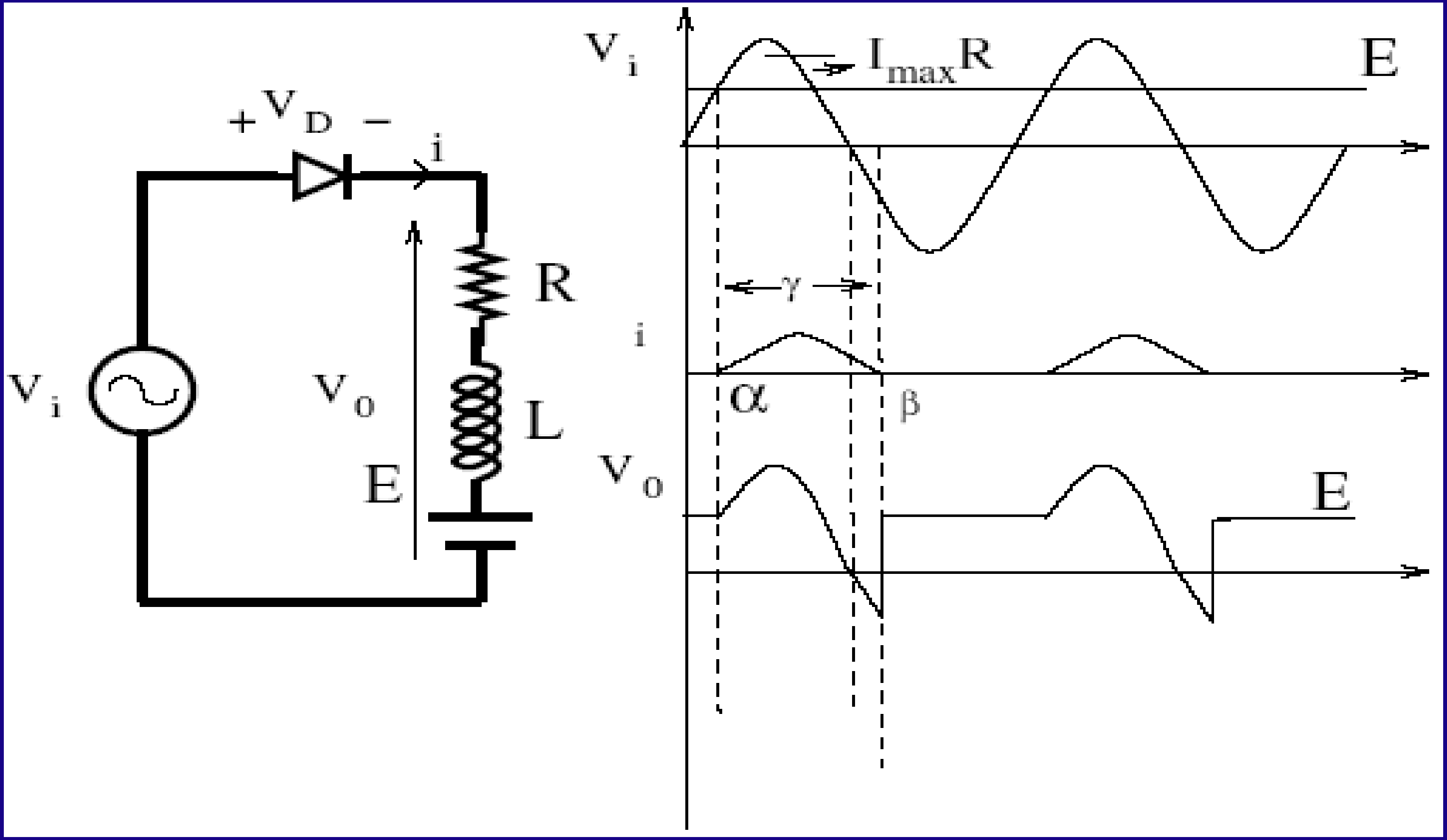
$$V_o = E, \text{ for } 0 < \omega t < \alpha$$

$$V_o = V, \text{ for } \alpha < \omega t < \gamma$$

$$V_o = E, \text{ for } \gamma < \omega t < 2\pi + \alpha$$

$$i = 0 \text{ at } \beta \text{ when } +\text{ve } L\frac{di}{dt} = -\text{ve } L\frac{di}{dt}$$

Case – 3: R-L-E Load



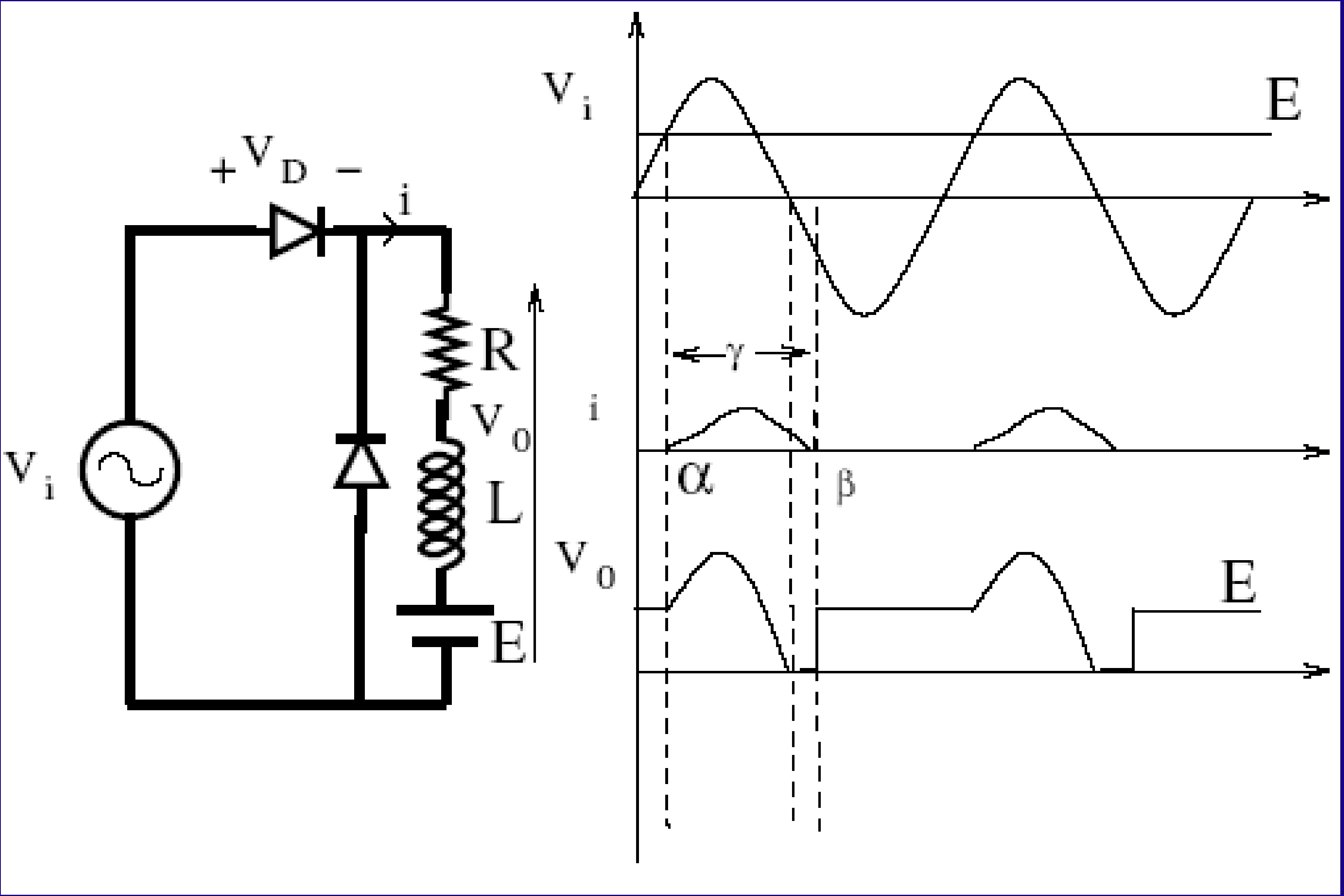
$$\alpha = \omega t = \sin^{-1}\left(\frac{E}{V_m}\right)$$

$$V_i = Ri + E + L\frac{di}{dt}$$

$$i = I_{max}, \qquad \pi/2 < \omega t < \pi - \alpha$$

$$V_i = E + RI_{max} \qquad \because L\frac{di_{max}}{dt} = 0$$

Case – 4: R,L, Freewheel Diode



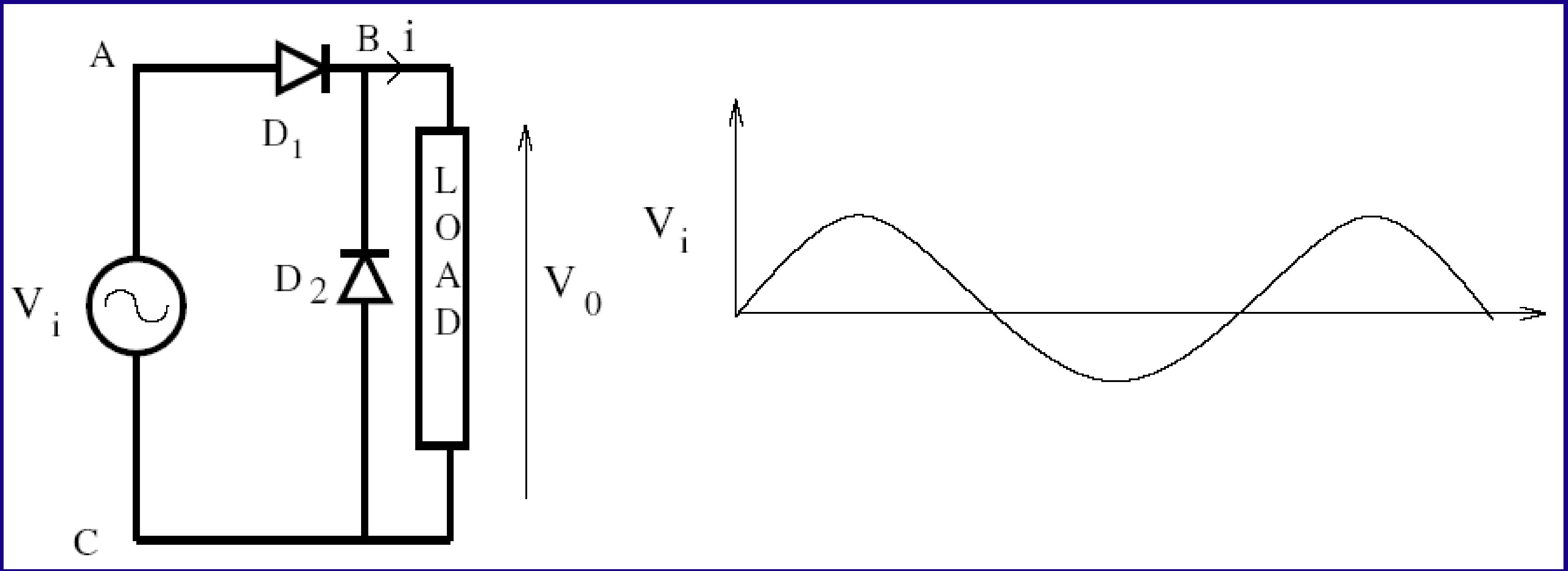
$-$ve voltage can not appear across the load

For $\pi < \omega t < \beta$, 'i' starts flowing through freewheeling diode.

$V_0 = 0$, beyond β, $V_0 = E$

Observations

- when diode is OFF, V_0 depends on Load
- when diode is ON, $V_0 = V_i$



Assume that the load current is continuous

Either D_1 or D_2 should be ON

In +ve half D_1 is ON, D_2 can not conduct.

Proof:

Potential of Pt. A > Potential of Pt. C

Assume D_2 is ON

Potential of Pt. C = Potential of Pt. B

Potential of Pt. A > Potential of Pt. B

+ve voltage across D_1 is not possible

Assumptions is wrong.

$\therefore$ If 'i' is continuous in the +ve half D_1 conducts and during -ve half D_2 conducts.

$\Rightarrow$ Independent of type of load

Conclusions

- $\gamma \uparrow$ with load 'L'.
- For diode to conduct $V_D = 0$,

  V_A potential need not be +ve.
- Use of freewheeling diode $\uparrow \gamma$.
- If 'i' is discontinuous & load is R-L-E

  then $\alpha = \sin^{-1}(\frac{E}{V_m})$
- If 'i' is continuous, $\alpha = 0$,

independent of load $\Rightarrow$ due to $L\frac{di}{dt}$