Madmohan
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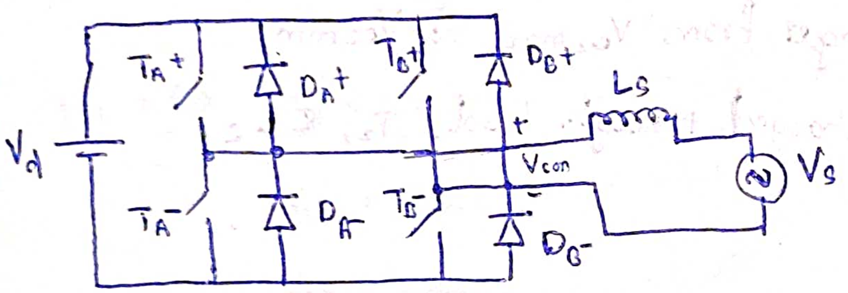
Switched Mode Rectifier

Used for Induction motor regenerative actions. eg: converting AC power to DC.

* Rectifier mode of operation occurs during regenerative braking of an induction motor load connected to an DC source through an inverter.
* Kinetic energy associated with motor & load is recovered and fed back to DC source.



(Learn Sine PWM)

V_s represents backemf of single phase Induction motor

A single phase induction motor is connected to DC source through converter.

L_s is winding inductance

* V_s is Back emf - sinusoidal with fundamental freq (freq of $V_{control}$)

$$V_{con} = V_{Ls} + V_s$$

$$V_{Ls} = L_s \frac{di_s}{dt}$$

Fundamental component of Converter 1, $V_{con1} = V_{Ls1} + V_s$

Backemf $V_s = V_{con1} - V_{LS1} = V_{con1} - j\omega L_s I_{s1}$

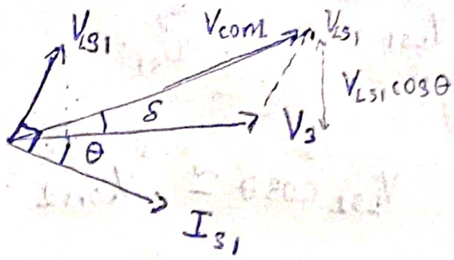
* Direction of i_{s1} - decides the inverter and rectification modes of operation.

Inversion mode

* V_s remains const for small instant.

* I_{s1} is laging V_s by angle θ

* V_{con1} leads V_s by one angle δ.



* Real power at AC side is $P = V_s I_{s1} \cos\theta$

$$= V_s \frac{V_{LS1}}{\omega L_{S1}} \cos\theta$$

$$V_{LS1} \cos\theta \simeq V_{con1} \sin\delta$$

$$\boxed{P = \frac{V_s}{\omega L_{S1}} V_{con1} \sin\delta = \frac{V_s^2}{\omega L_{S1}} \cdot \frac{V_{con1}}{V_s} \sin\delta}$$

So V_{con1} leads V_s and active component of I_{s1} is in phase with V_s.

Power flows from dc side to AC side - in Inversion mode.

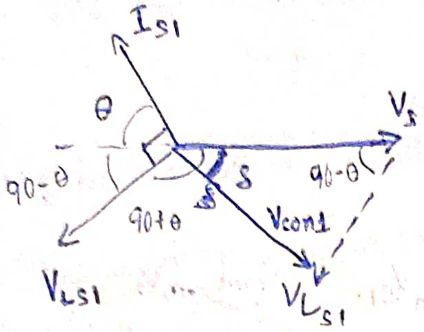
* Reactive power at AC side $Q = V_s I_{s1} \sin\theta$

$$= V_s \frac{V_{LS1}}{\omega L_{S1}} \sin\theta$$

$$V_{LS1} \sin\theta \simeq \left[V_{con1} \cos\delta - V_s\right]$$

$$\boxed{Q = V_s \cdot \frac{\left[V_{con1} \cos\delta - V_s\right]}{\omega L_{S1}} = \frac{V_s^2}{\omega L_{S1}} \left[\frac{V_{con1}}{V_s} \cos\delta - 1\right]}$$

Rectifier Mode



* V_{con1} lags the V_s by an angle δ. (angle from V_s to I)

* Real power at AC side is $P = V_s I_{s1} \cos(180 \pm \theta)$

$$P = -V_s \frac{V_{Ls1}}{\omega L_s} \cos\theta$$

$$=$$

$$V_{Ls1} \cos\theta \simeq V_{con1} \sin\delta$$

$$\boxed{P = -V_s \cdot \frac{V_{con1}\sin\delta}{\omega L_s} = \frac{-V^2}{\omega L_{s1}} \cdot \frac{V_{con1}}{V_s} \sin\delta}$$

Reactive power $Q = V_s I_{s1} \sin(180+\theta)$

$$= -V_s I_{s1} \sin\theta$$

$$= -V_s \frac{V_{Ls1}}{\omega L_{s1}} \sin\theta$$

$$V_{Ls1} \sin\theta \approx \left[\cancel{V_{con1}\cos\delta}\ V_s - V_{con1}\cos\delta\right]$$

$$\cancel{Q} = \frac{\cancel{V_s}^2}{\omega \cancel{L}_{s1}} \left[\frac{\cancel{V_{con1}}}{\cancel{V_s}} \cos\delta\right] \qquad Q = -\frac{V_s^2}{\omega L_{s1}} \left[1 - \frac{V_{con1}}{V_s} \cos\delta\right]$$

$$\boxed{Q = \frac{V_s^2}{\omega L_{s1}} \left[\frac{V_{con1}}{V_s} \cos\delta - 1\right]}$$

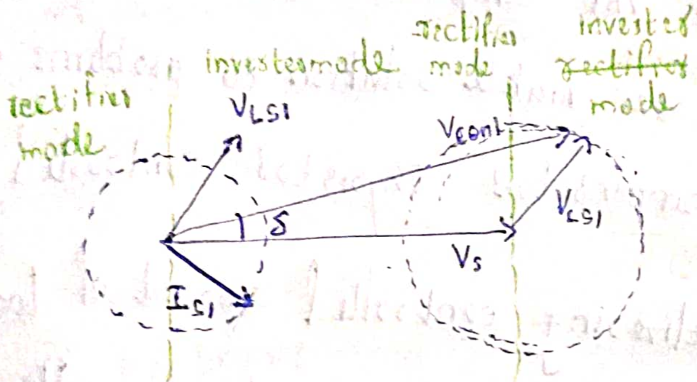
* Q is sum of reactive power absorbed by converter & inductance L_s
* At very high switching frequencies L_s can be made very small

* Then Q is the reactive power absorbed by the converter.

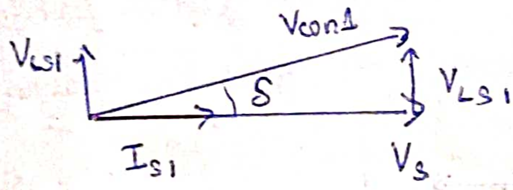
Suresh Kumar sir's book read

* For a given value of AC side potential (back emf) V_s and the chosen value of inductance L_s, desired values of P & Q can be obtained by controlling magnitude and phase angle δ of V_{con1}.

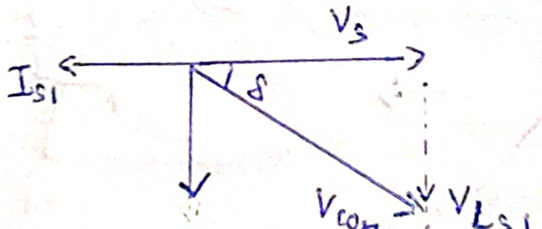
* V_{con1} can be varied by keeping the magnitude of I_{s1} and V_s const.



* Inversion at upf



Rectification at upf



In both cases

$$V_{con1} = \sqrt{V_s^2 + (\omega L_s I_{s1})^2}$$

* For desirable magnitude and direction of P & Q, magnitude of V_{con} and phase angle δ must be controlled.

* PWM converter works in linear range ($m_a \le 1$)

* V_d must be sufficiently large magnitude $[V_d > \sqrt{2}\, V_s]$

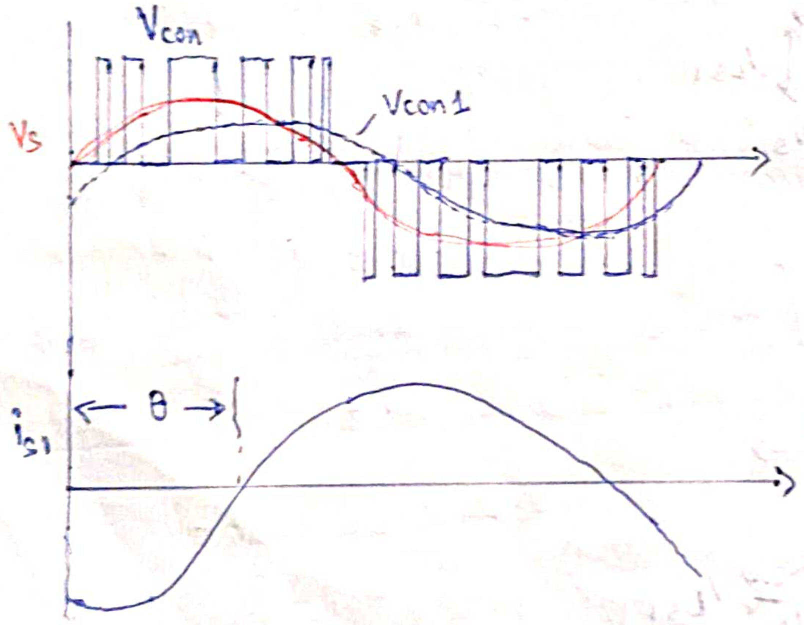
* Reactive power flow can be controlled by introducing a phase shift between i_s and V_s.

* PWM VSI based STATIC VAR compensation.

* PWM VSI based SVC, are viable solution to problems associated with passive shunt compensators Thyristor controlled reactors.

* They are capable of delivering controlled amount of lagging and leading Vars to load or a bus system rapidly.

*



Resonance Converter

27/8/22

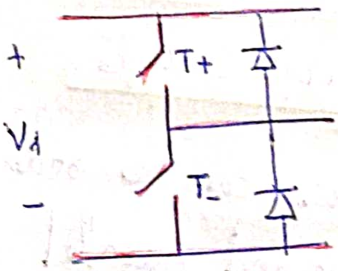
High frequency switch mode PWM converters.

Advantages

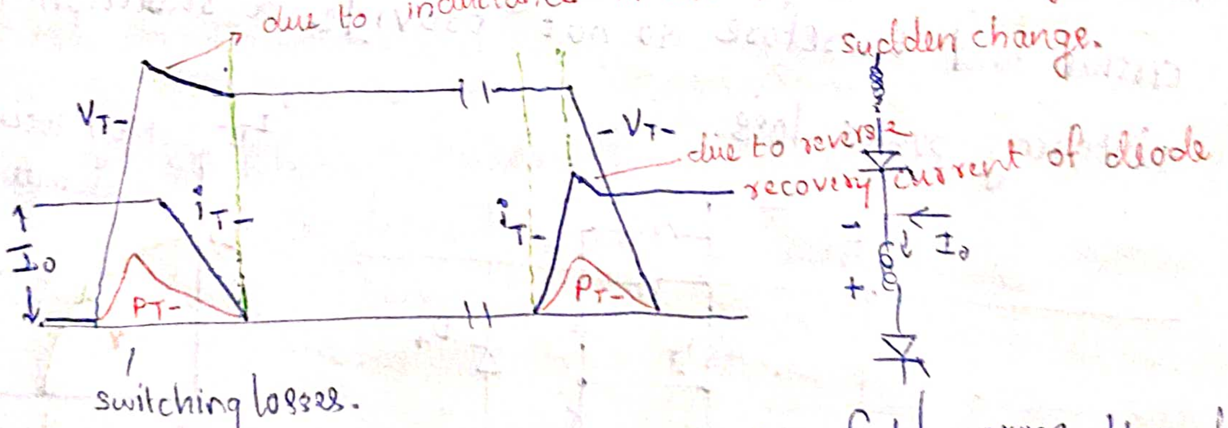
1. High efficiency
2. Devices are operated at maximum efficient points - at cut off & saturation points.
3. Size and cost are much lower especially at high power level.

Limitations

1. Greater circuit complexity compared to linear converters.
2. Controllable switches (operated in a switched mode) are required to turn on and turn off entire load current during each switching



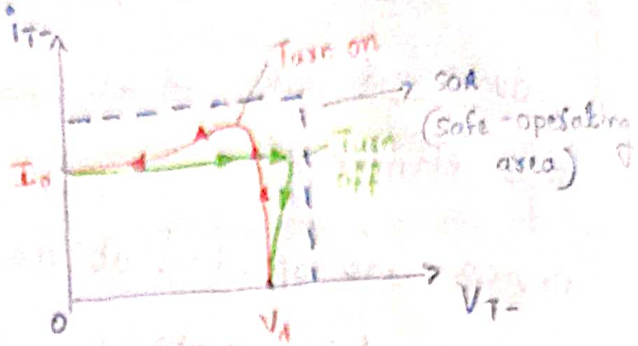
See diag of switched mode rectifier.



when voltage is blocked - high electrostatic field across the device.
when high current passes - high magnetic field.

3. So this high $\frac{di}{dt}$ and $\frac{dv}{dt}$ during switching causes Electromagnetic interferences.

4. High stress levels on devices that increases linearly with switching frequency of pwm.
5. Higher switching loss at high frequencies.

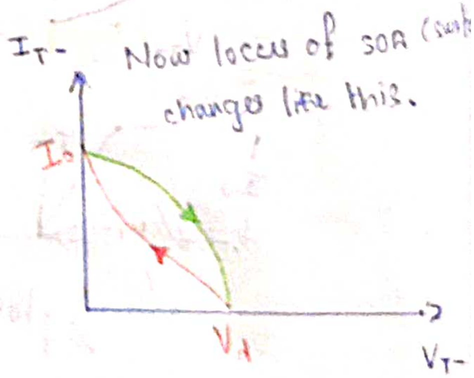


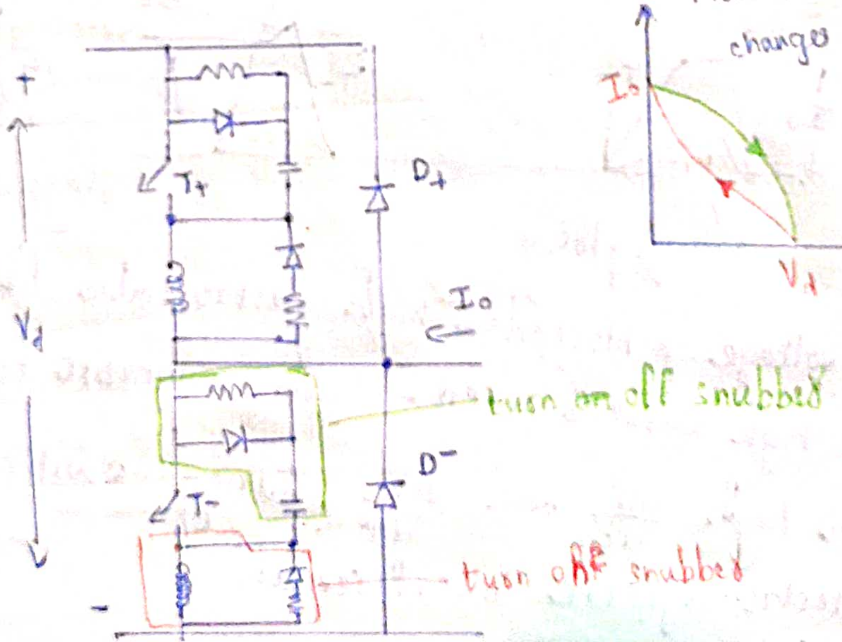
V_d & I_d should be with in SOA.
So SOA is an indication of power loss in the switches.
In order to minimise the loss, we use snubber circuits. (it only diverts voltage & circuit, amount of energy lost remains same)

Locus of point voltage to current during turn on & current to voltage during turn off.

Dissipative snubber Circuits.

1. The switches stress can be reduced by connecting simple dissipative circuits in series and parallel with switches in the switch-mode converters.
2. These snubbers shift switching power loss from switch to snubber circuit and therefore do not provide a reduction in overall switching power loss.

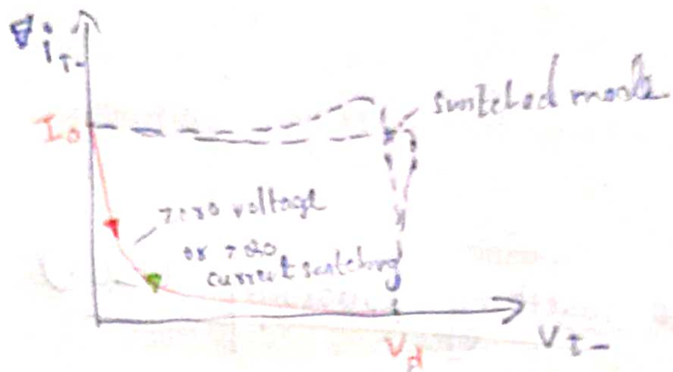




③ To minimize these problems, switches are made to change the states of turn on to turn off or vice versa when voltage across it or current through it is zero at switching instant.

④ These topologies require some form of LC resonance and hence, they are classified as resonant converters.

⑤ The switch voltage and current are shaped so as to get zero voltage and / or zero current during switching and they are known as soft switching converters



Advantages of soft switching resonant converters.

① reduced power loss at high switching frequency

② Less size and hence high power density.

③ High efficiency

④ Less stress on devices.

Classification of resonant converters

Resonant Switch Converters.

Additional circuit elements are added to get zero voltage/zero current switching and are called resonant switch converters.

① zero cv

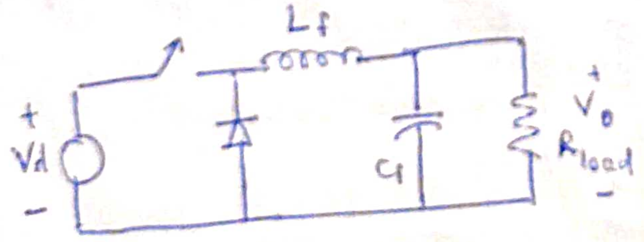
I Zero current switching topology. (ZCS)

① LC resonance is utilized to shape the switch voltage and current to provide zero-voltage and/or zero current switching.

② During one switching period, there are resonant as well as non-resonant operating intervals. Therefore these converters are also known as quasi-resonant converters.

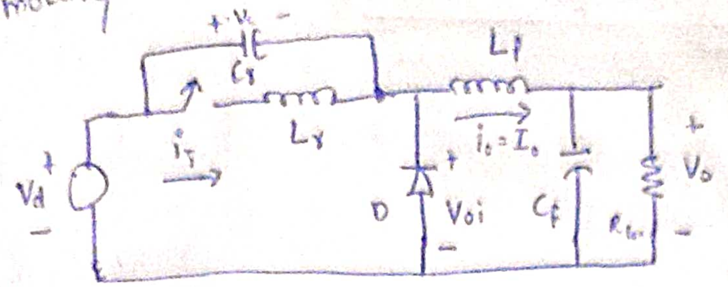
zero current switching (ZCS) Converters

① The switch turn on and turn off occurs at zero current.



Buck converter

we modify this circuit to for zero current



Initial Conditions

* Let the switch is in the off state
  - → C_r charged to V_d
  - → $V_c = V_d$, $i_T = 0$
* Diode in on state.
* At $t = t_0$ switch is turned on.

* At $t=t_0$

→ Due to presence of inductance , turn on occurs at zero current.
(current cannot instantly change to zero)

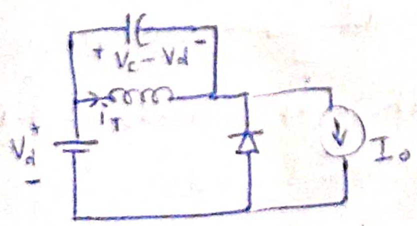
→ L_r and C_r are shorted through the switch (V_d accross L_r
- current ~~voltage~~ increase linearly)

→ $V_{oi} = V_d - V_c = 0$

→ ~~$V_{oi} = V_d - V_c = 0$~~ Diode continue to conduct.

→ $V_{Lr} = V_c = V_d$

* From $t_0 \to t_1$



$V_{Lr} = V_d$

i_T rises linearly

i_T less than i_{Lf} so $i_D = I_o - i_T$

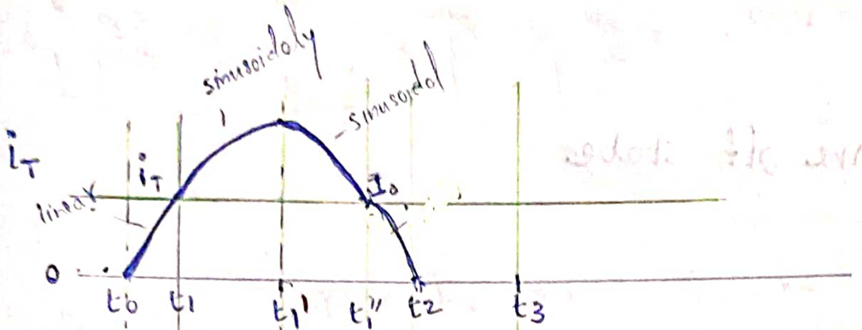
D continues to conduct until $i_d = I_o$

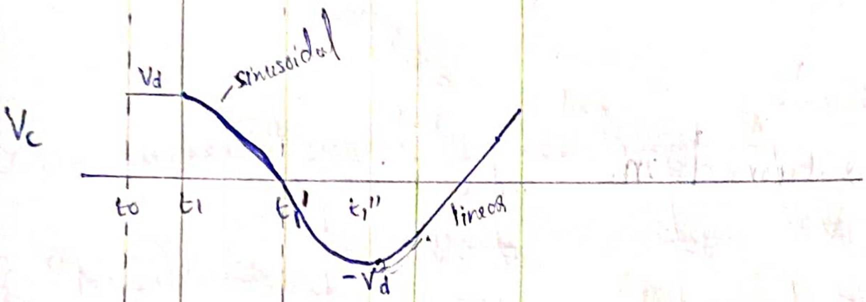
$V_c = V_d$ (since Diode conducting)

* At $t = t_1$

→ i_T is equal to i_{Lf}

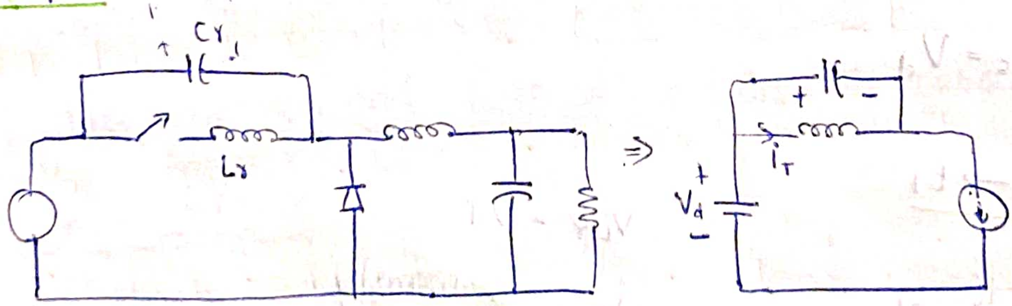
→ D stops conduction





* $t_1 \to t_1'$: diode offs

→



→ C_r discharge from V_d to zero through switch & L_r.

→ $i_c = V_d \sqrt{\frac{C_1}{L_1}} \, \omega_0 t$

→ $i_T = I_0 + i_c$

* At $t_1' \rightarrow t_1''$

→ i_c decreases sinusoidaly to zero

→ At t_1'' → $i_c = 0$

$i_T = I_0$

V_c reaches $-V_d$

* From $t'' - t_2$

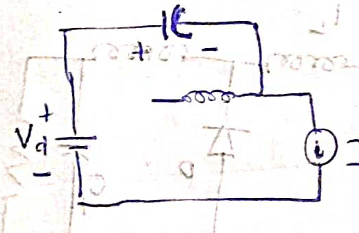
→ Capacitor discharges sinusoidaly in -ve direction towards load circuit.

→ $i_T = I_0 - i_0$

→ i_T reduces to zero sinusoidaly.

→ switch is turned off naturally.

* From $t_2 - t_3$



~~the~~ Capacitor discharges through the load circuit

→ $i_c = I_0$ which is constant.

→ V_c rises linearly to V_d & $i_c = 0$

→ when capacitor potential = V_d - diode conducts.

→ Off period of buck converter begins.

* From $t_3 - t_4$

→ switch is off

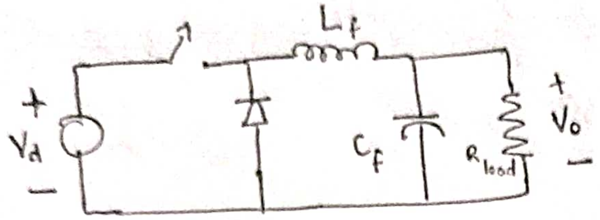
→ Load current free wheels through diode

→ $V_c = V_d$ & ~~I_T~~ $i_T = 0$

4/5/22

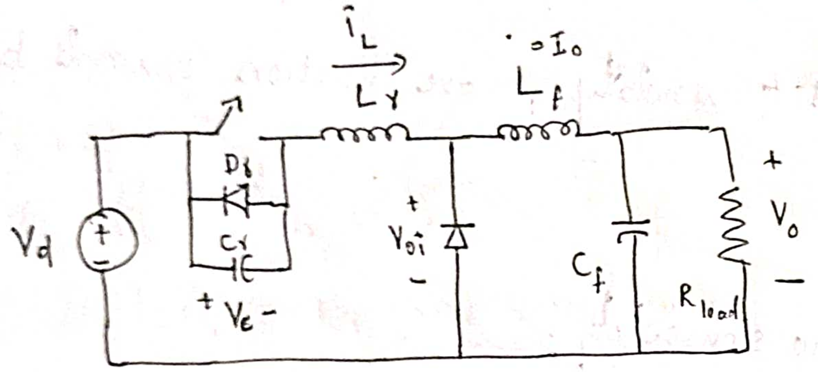
Zero Voltage switching (ZVS) Converters.

① The switch turn on and turn off occurs at zero voltage.

② 

Initially when switch is closed entire current flows through switch.
When we suddenly switch off - it causes cracking (power loss) of switch.

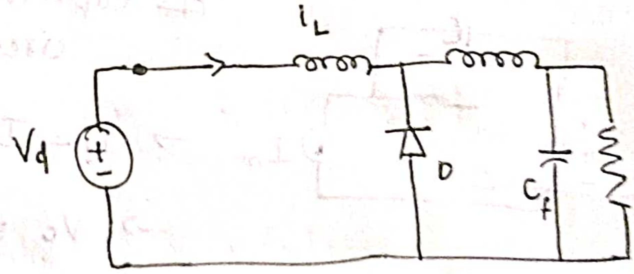
③ Such situation should be avoided by - zero voltage switching



④ Initial condition,

The switch is in the on state, D is off - const load current flows through L_r and L_f.

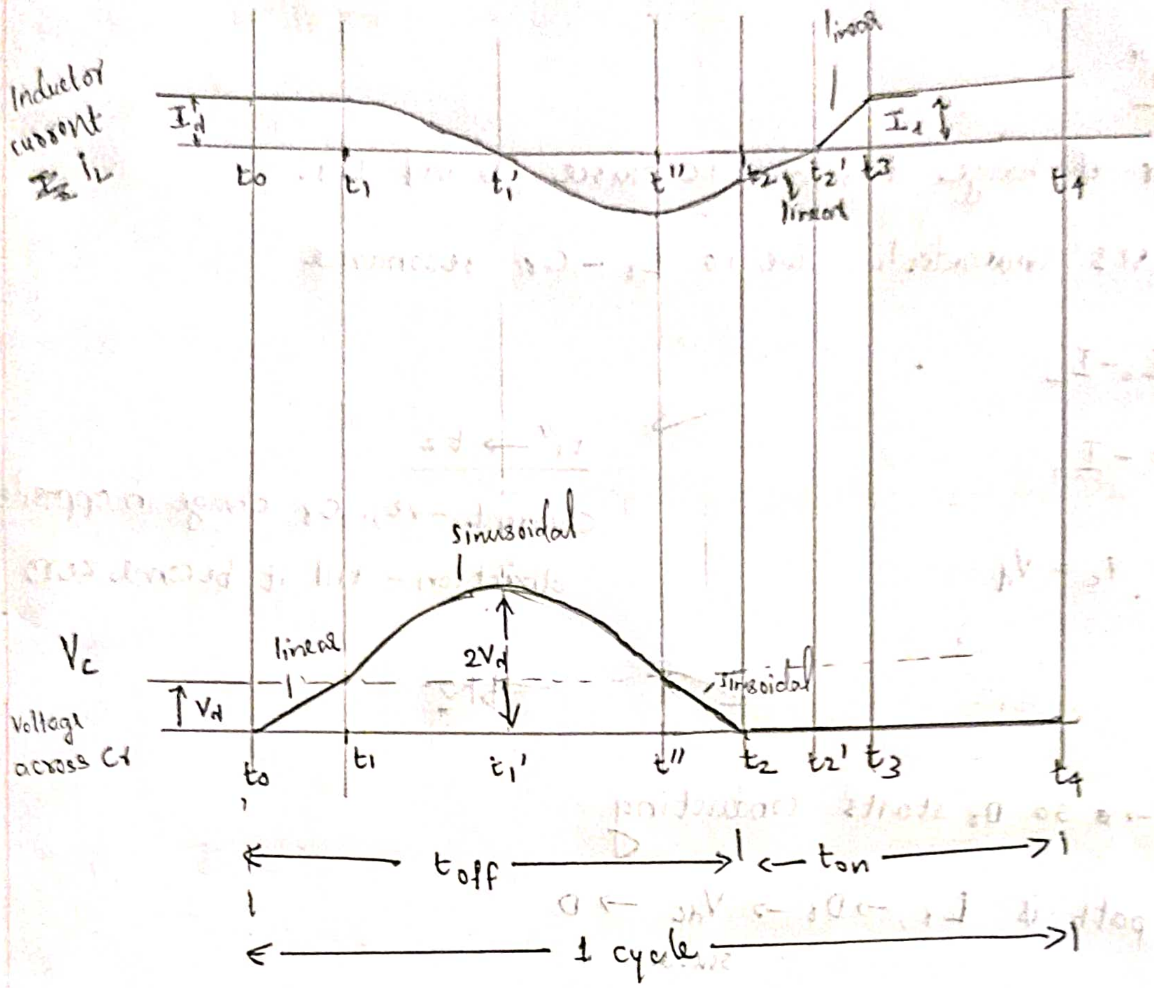
→ D is off, D_r is also off
→ $V_c = 0$ (C_r cap)
→ i_L = Load current I_o



→ $V_{oi} = V_d$ (drop across L_r is zero since const current flowing)

⑤ At $t = t_o$ switch is turned off at zero voltage condition, because of C_r.

∴ Device is turned off at zero voltage due to C_r



$t_0 \to t_1$

→ i_L which is constant load current flows through the capacitor
↳ since L_r demands same current.

→ V_c rise linearly from zero to V_d.

→ At $t = t_1$, $V_c = V_d$

So $V_{oi} = 0$ → so the diode starts conducting
$= V_c - V_d$

$t_1 \to t_1'$

→ Switch is off & D is on - so C_r & L_r resonates.

→ In LC oscillation C_r gets charged to potential greater than V_d due to negative voltage across L.

$2V_d$

→ So when $V_c > V_d$,

At t_1', i_L is zero, V_c is maximum $= V_d + V_{Lr}$.

$t_1' \rightarrow t_1''$

→ Capacitor discharge through DC source, D and L_r.

→ i_L reverses sinusoidaly due to $L_r - C_r$ resonance

→ $i_D = I_o - I_L$

$i_L = -I_o$

At t_1'', $V_c = V_d$

→ $t_1'' \rightarrow t_2$

Current -ve, C_r charge in opposite direction - till it become zero

At t_2

$V_{dr} = 0$ → so D_r starts conducting

Current path is $L_r \rightarrow D_r \rightarrow V_{dc}$ source $\rightarrow D$

V_c continuous to be zero - so

$t_2 \rightarrow t_2'$

D & D_r conduct.

$V_{Cr} = 0$

$V_{Lr} = V_d$ → so i_L rises linearly to zero through D_r

Switch is reverse biased while D_r is conducting.

At t_2'

→ $i_L = i_{Dr} = 0$ → so D_r become off. and switch goes to on state - if gating signals are operated.

→ Gating signals can be applied after T_2.

→ V_{cr}, continuous to be at zero potential and turn on occurs at zero Voltage

→ Peak Voltage ~~vo~~ across switch is $2V_d$.

→ Reverse voltage across diode $D_r = 2V_d$.

→ If switch on at t_2' → when $i_L = i_{Dr} = 0$ and D_r is off

Turn on occurs at zero Voltage.

$t_2' \rightarrow t_3$

i_L rises linearly to I_o → D still conducts $i_D = I_o - i_L$

At t_3

$i_D = 0$ – D is off