ElCoM
ELECTRICAL COMPUTER MECHATRONICS

تقدم لجنة ElCoM الاكاديمية

دفتر لمادة:

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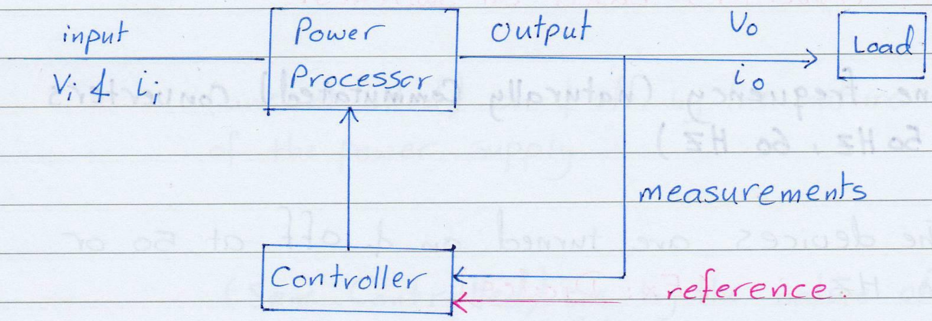


Block diagram of power electronic system (Generic)

- Types of Power Processors:

1) DC
   a) regulated magnitude
   b) adjustable magnitude.

2) AC
   a) Constant frequency adjustable magnitude.
   b) adjustable frequency adjustable magnitude.

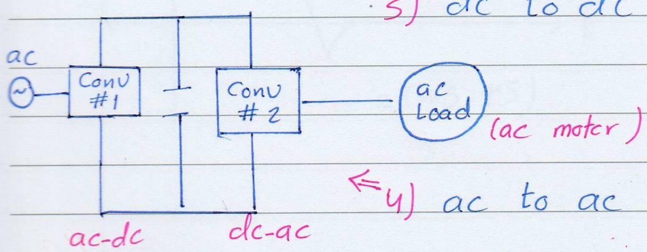
Power Converters → Rectifiers
→ Inverters.

Converters:

1) ac to dc = rectifier ($1\phi, 3\phi$) → Controlled / unControlled

2) dc to ac = inverter ($1\phi, 3\phi$)

3) dc to dc = Converter → Step up / step down / Stepup_step down / full bridge



4) ac to ac = rectifier + inverter

- Types of converters based on switches:

1) Line frequency (naturally Commutated) converters (50 HZ, 60 HZ)

The devices are turned on & off at 50 or 60 HZ (Ex: Diodes)

2) Switched (Forced commutated) Converters (15 kHZ - 30 kHZ)

The devices are turned on & off at frequencies much higher than the line frequency [15 kHz - 30 kHz]

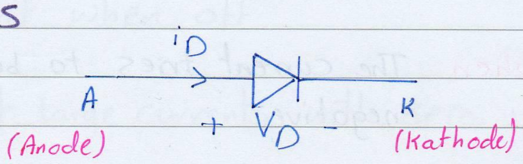
- According to the degree of controllability :-

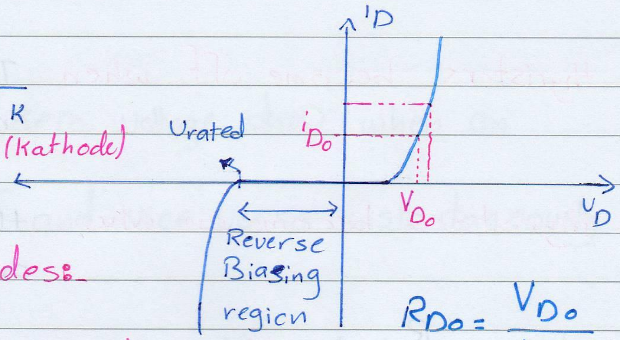
1) Diodes: (uncontrolled) on & off by the nature of the power supply

2) Thyristors: (Semi-Controlled) on by the nature of the power supply + additional control signal and off by the nature of the supply.

3) Controllable Switches: (Controlled) on & off by additional control Signal (BJT, MOSFET, GTO, IGBT)

1] Diodes





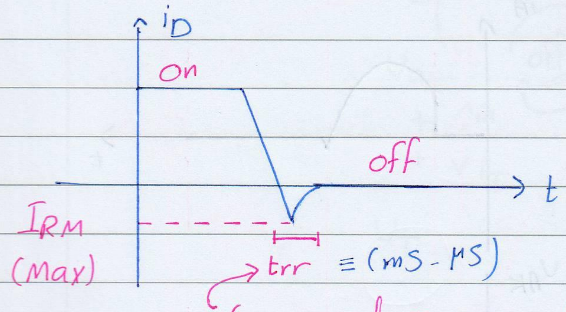
$R_{D_0} = \dfrac{V_{D_0}}{i_{D_0}}$

i-V Char.

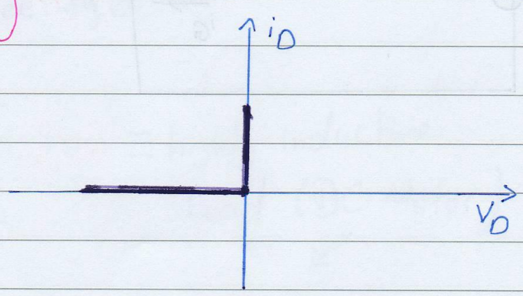
- Power Semi-Conductor diodes:-

1) Schottky diodes ⇐ (50-100) Vrated
2) Fast recovery diodes
3) Line Frequency diodes.

*check Vrated From the book

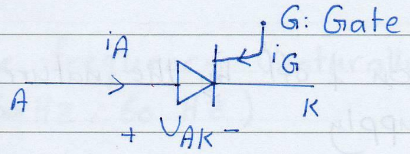


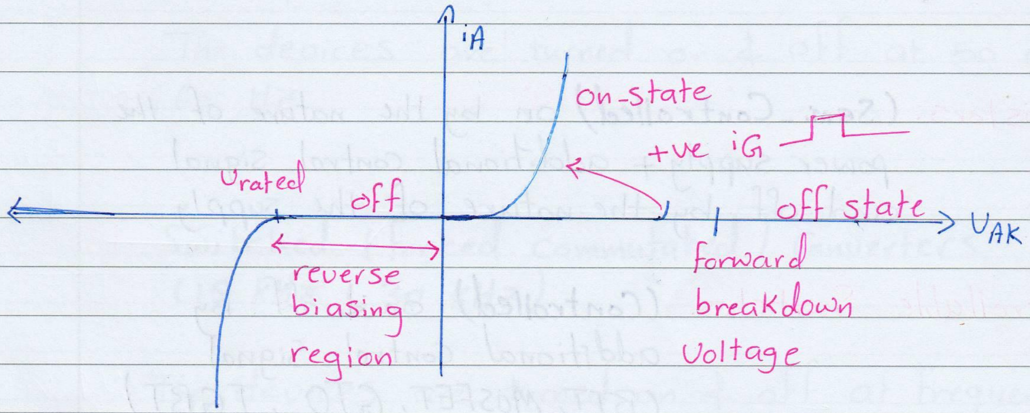
$t_{rr} \equiv$ (mS - μS)
(reversed recovery time)



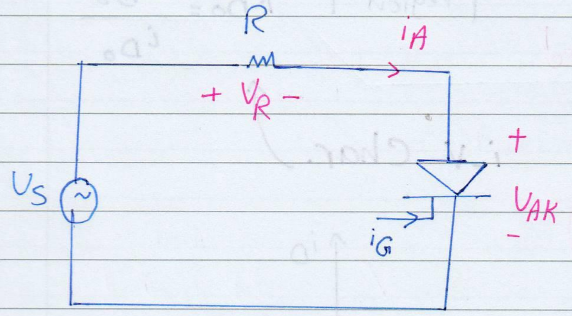
idealized i-V char.

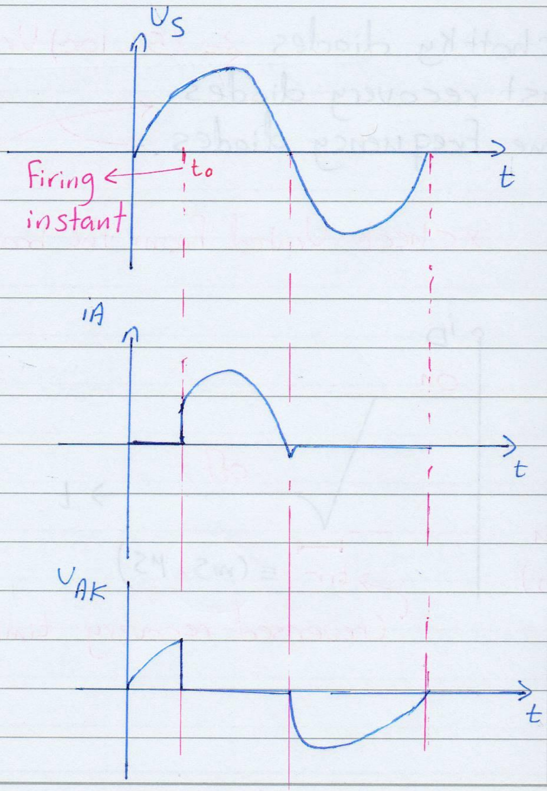
2] Thyristors:

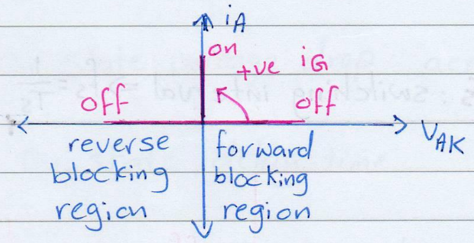




- The thyristors become off when: The current tries to be negative
- The thyristors become on when: +ve gate & +ve voltage are applied.







← (ideal)

Types of thyristors:

1) Phase Controlled thyristors
2) Inverter grod thyristors.
3) Light activated thyristors.

Desired characteristics of controllable switches (BJT, MOSFET, IGBT, GTO):

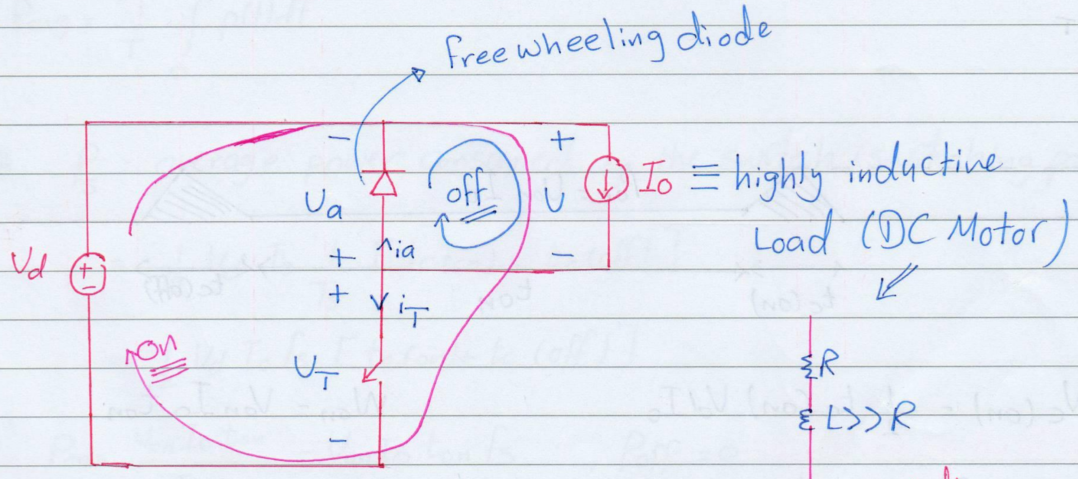
1) Block large forward and reverse voltages with zero current when off.

2) Conduct large currents with zero voltage drop when on.

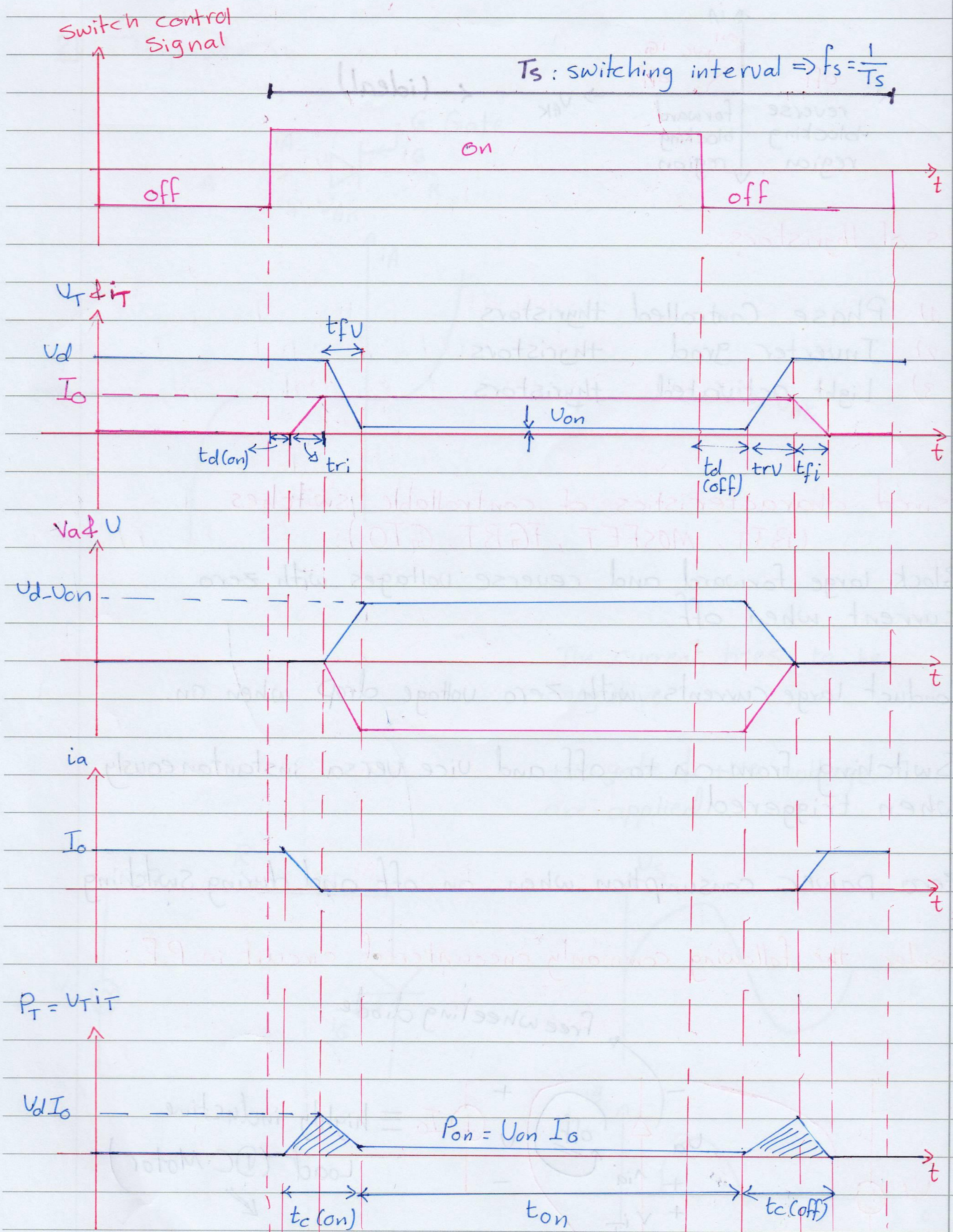
3) Switching from on to off and vice versa instantaneously when triggered

4) Zero power consumption when on, off and during switching

Consider the following commonly encountered circuit in P.E:



$V = L\frac{di}{dt}$



$W_{c\,(on)} = \frac{1}{2}\, t_{c\,(on)}\, V_d I_o$ $\qquad W_{on} = V_{on} I_o t_{on}$

$W_{c\,(off)} = \frac{1}{2}\, t_{c(off)}\, V_d I_o$

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- V_{on}: On-State voltage drop across the switch.

$t_{d(on)}$: On-state delay time

t_r: rising time for the current

t_{fv}: falling time for the voltage.

$t_{d(off)}$: off-State delay time

t_{rv}: rising time for the voltage.

t_{fi}: falling time for the current

$$V_d = V + V_T$$

$$\frac{dV_d}{dt} = \frac{dV}{dt} + \frac{dV_T}{dt}$$

$$0 = \frac{dV}{dt} + \frac{dV_T}{dt}$$

$$\frac{dV}{dt} = -\frac{dV_T}{dt}$$

$$I_o = i_a + i_T$$

$$\frac{dI_o}{dt} = \frac{di_a}{dt} + \frac{di_T}{dt} = 0$$

$$\frac{di_a}{dt} = -\frac{di_T}{dt}$$

$\Rightarrow V_a + V = 0 \Rightarrow V_a = -V$

$\Rightarrow$ $P_{avg} = \frac{1}{T}\int_0^T p(t)\,dt$

P_s = average power consumed by the switch (switching power)

$$= \frac{1}{2} V_d I_o \frac{1}{T_s}\left[t_{c(on)} + t_{c(off)}\right]$$

$$= \frac{1}{2} V_d I_o f_s \left[t_{c(on)} + t_{c(off)}\right]$$

$P_{on} = \frac{V_{on} I_o t_{on}}{T_s} = V_{on} I_o t_{on} f_s$, $P_{off} = 0 \Rightarrow i_T = 0$ during the off State

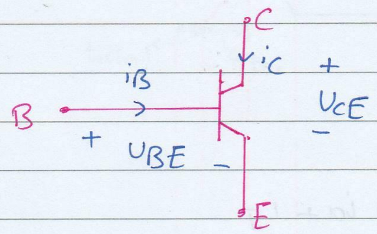
$P_{total} = P_s + P_{on} + \underset{0}{P_{off}} \Longrightarrow$ $\eta\%_{switch} = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{total}} \times 100 = \frac{(V_d - V_{on}) I_o}{(V_d - V_{on}) I_o + P_s + P_{on}}$

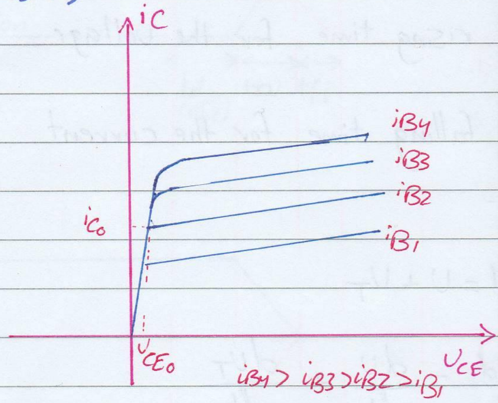
P.7

* From the above discussions, the following cha. in the Controllable ~~####~~ switches are desired.

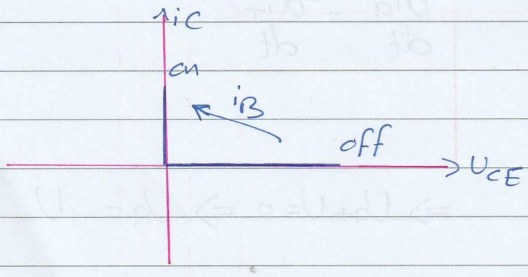
1) Small leakage (Reversed) current in the off_state.
2) Small on_state voltage drop.
3) Short turn_on & turn_off time intervals. ($P_s \approx 0$)
4) High on state current rating.
5) Small power consumed by the control circuit.

3] Bipolar Junction Transistor (BJT)

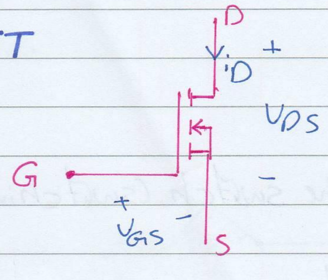


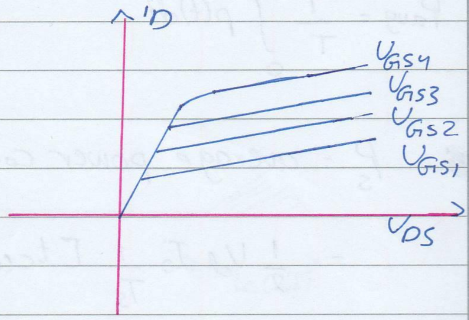


Current controlled device (i_B)

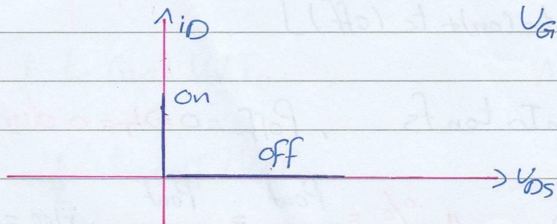


4] MOSFET



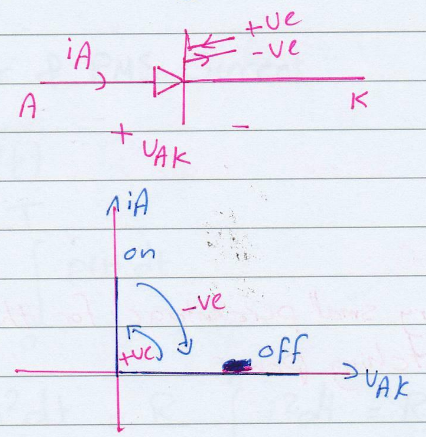


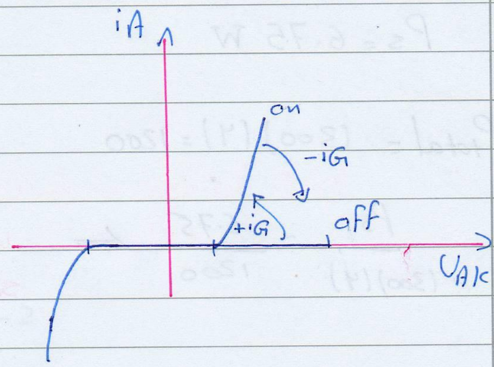
$U_{GS4} > U_{GS3} > - -$



Voltage Controlled device.

5] Gate - Turn - Off Thyristors





Description: Like the thyristor, GTO is turned on by +ve gate pulse.
Unlike the thyristor, GTO is turned off by -ve gate pulse.

- Idealized cha. of controllable switches:

1] Zero on-state voltage drop.
2] Zero reversed current in the off-state.
3] Zero time duration for switching.
4] Power required for the control circuit is zero

$$\left[\begin{array}{l} P_{on} = \text{Zero} \\ P_{off} = \text{Zero} \\ P_s = \text{zero} \end{array}\right]$$

Note: The switches will be treated in this course as ideal, because:

1] On-state voltage drop is very small compared with the operating voltage.
2] Off-state reversed current is very small compared with rated current.
3] Switching time is very small compared with the switching frequency

P_2_1] $t_{ri} = 100\ nS$, $t_{fv} = 50\ nS$, $t_{rv} = 100\ ns$, $t_{fi} = 200\ nS$.
$V_d = 300\ V$ $I_o = 4A$, $P_s = ?$

$$P_s = \frac{1}{2} V_d I_o f_s \left[t_{c(on)} + t_{c(off)}\right] = \frac{1}{2}(300)(4) f_s [\underbrace{t_{ri} + t_{fv}}_{t_{c(on)}} + \underbrace{t_{rv} + t_{fi}}_{t_{c(off)}}]$$

$$P_s = 2.7\times10^{-4} f_s \Rightarrow P_s \propto f_s.$$

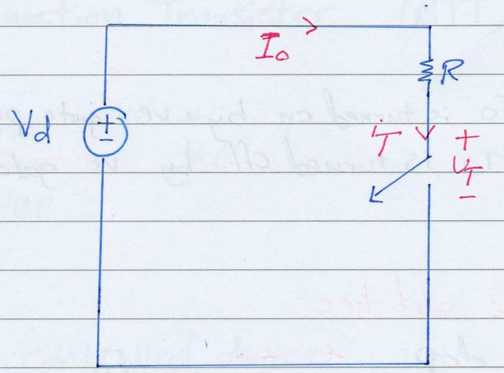
⇒ If $f_s = 25\ KHZ$

$P_s = 6.75\ W$

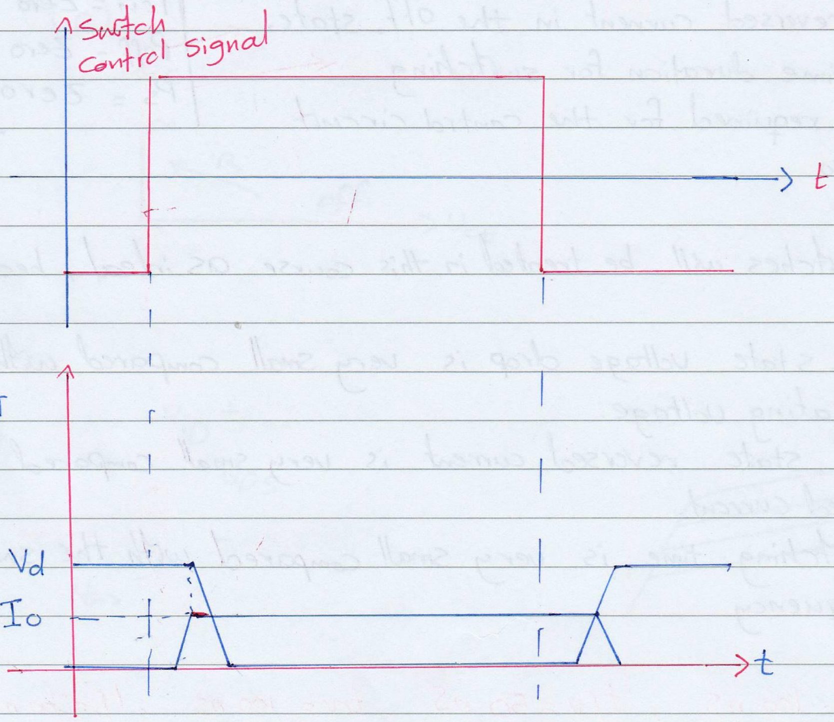
$P_{total} = (300)(4) = 1200$

$\frac{P_s}{(300)(4)} = \frac{6.75}{1200}$ ⇐ very small percentage for the switching power.

P-2-2)



$I_o = \frac{V_d}{R}$



Chp3: Review Of Basic Electrical Circuits Concepts

Average Power & RMS Current

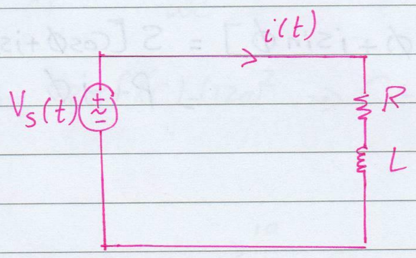
$P(t) = V(t)\,i(t) \Rightarrow$ instant. Power.

$$P_{avg} = P = \frac{1}{T}\int_0^T p(t)\,dt$$, $P = P(t) \Rightarrow$ in case of 3_ϕ system.

$$P_{avg} = \frac{1}{T}\int_0^T R i^2 dt = \frac{R}{T}\int_0^T i^2 dt = R I^2$$

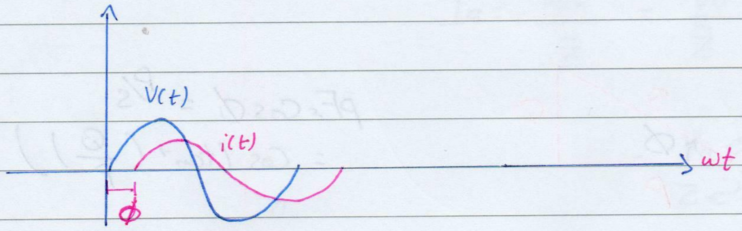
$$\Rightarrow \quad I = \sqrt{\frac{1}{T}\int_0^T (i(t))^2 dt} \quad \text{rms.}$$

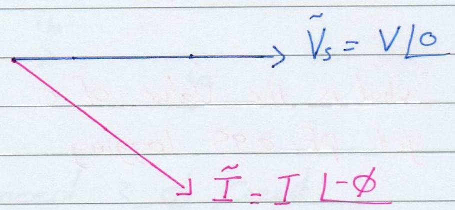
Steady State ac waveforms with sinusoidal voltages & Currents.



$v_s(t) = \sqrt{2}\,V\cos(\omega t)$

$i(t) = \sqrt{2}\,I\cos(\omega t - \phi)$





$\tilde{V} = Ve^{j0} = V\cos(0) + jV\sin(0)$, $\tilde{I} = Ie^{-j\phi} = I\cos\phi + jI\sin(-\phi)$

$$\tilde{Z} = \frac{\tilde{V}}{\tilde{I}} = \frac{Ve^{j0}}{Ie^{-j\phi}} = \frac{V}{I}e^{j\phi} = \frac{V}{I}[\cos\phi + j\sin\phi]$$

rectangular form

$$\tilde{Z} = Ze^{j\phi} \Leftarrow \text{Exponential form.}$$

- Power, Active power, Reactive power, Apparent power and Complex Power.

$$\tilde{S} = \tilde{V}\tilde{I}^{*} \Rightarrow \text{Complex power}$$

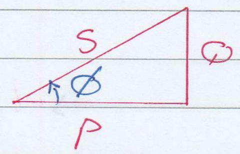
$$= Ve^{j0}(Ie^{-j\phi})^{*} = VIe^{j\phi}$$

$$= VI[\cos\phi + j\sin\phi] = S[\cos\phi + j\sin\phi]$$

$$= P + jQ$$

$$|\tilde{S}| = VI \Rightarrow \text{apparent power.}$$

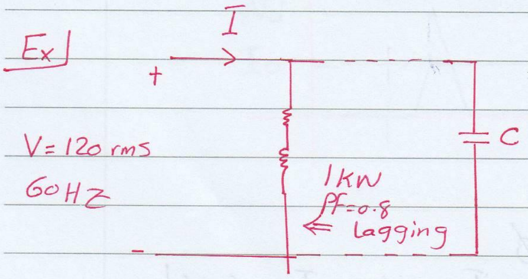
$$P = VI\cos\phi \qquad Q = VI\sin\phi$$



$$pF = \cos\phi = P/S$$

$$= \cos\left(\tan^{-1}\left(\frac{Q}{P}\right)\right)$$

Ex)



what is the Value of C to get pF=0.95 lagging.

Solution:- $pF = \frac{P}{S} \Rightarrow S = \frac{P}{PF} = \frac{1000}{0.8} = 1250$ VA before "C"

$$Q = \sqrt{S^2 - P^2} = \sqrt{1250^2 - 1000^2} = 750 \text{ VAR}$$

$$\tilde{S} = 1000 + j750 \text{ VA}$$

with C:-

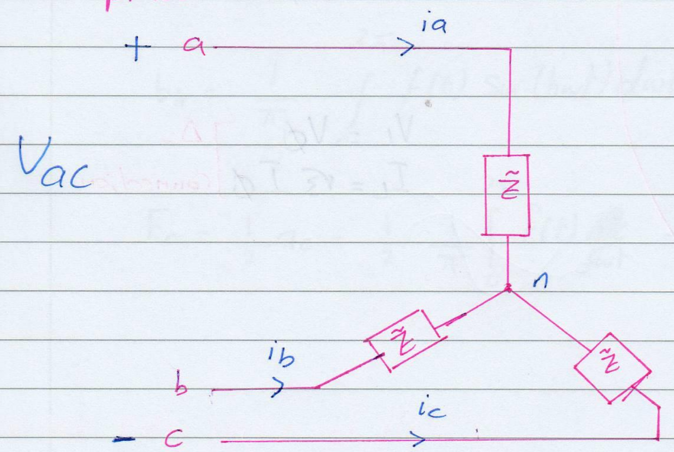
$$\tilde{S} = P + jQ - jQ_c$$

$$0.95 = \frac{P}{S} = \frac{1000}{\sqrt{1000^2 + (750 - Q_c)^2}} \Rightarrow Q_c = 421.3 \text{ VAR}$$

$$Q_c = \frac{U^2}{X_c} = \frac{V^2}{\frac{1}{wc}} = wcV^2$$

$$421.3 = (2\pi f)(C)(120)^2 \Rightarrow C = 77.6 \ \mu F.$$

Three-phase Circuits.



Balanced 3-ϕ Circuit.

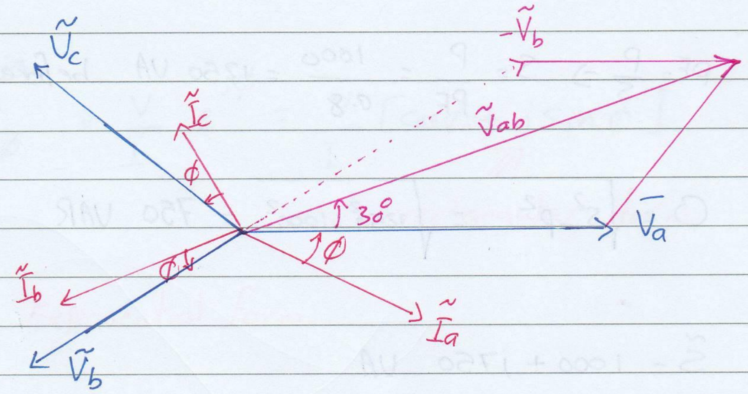
$$\tilde{I}_a = \frac{\tilde{V}_{an}}{\tilde{Z}} = \frac{\tilde{V}_a}{\tilde{Z}}$$

$$= \frac{V_a e^{j0}}{Z e^{j\phi}}$$

$$= \frac{V_a}{Z} e^{-j\phi}$$

$$\tilde{I}_b = \frac{V_a}{Z} e^{-j(\phi + 120^\circ)}$$

$$\tilde{I}_c = \frac{V_a}{Z} e^{-j(\phi - 120^\circ)}$$



$\tilde{V}_{ab} = \tilde{V}_a - \tilde{V}_b$

$$= V_a e^{j0} - V_b e^{j(0-120°)} = V_a e^{j0} - V_b e^{-j120}$$

$$= V\angle 0 - V\angle -120$$

$$= \sqrt{3}\, V \angle 30°$$

$P_{3-\phi} = 3 V_\phi I_\phi \cos\phi$ — Y & Δ

$Q_{3-\phi} = 3 V_\phi I_\phi \sin\phi$

$S_{3-\phi} = 3 V_\phi I_\phi$

$P_{3-\phi} = \sqrt{3}\, V_L I_L \cos\phi$

$Q_{3-\phi} = \sqrt{3}\, V_L I_L \sin\phi$

$S_{3-\phi} = \sqrt{3}\, V_L I_L$

$\left.\begin{array}{l} V_L = \sqrt{3}\, V_\phi \\ I_L = I_\phi \end{array}\right]$ Y_Connection

$\left.\begin{array}{l} V_L = V_\phi \\ I_L = \sqrt{3}\, I_\phi \end{array}\right]$ Δ_Connection

Non-Sinusoidal waveforms in steady-state.

⇒ The steady-state voltages and currents of power electronics are usually periodic but not sinusoidal.

Fourier Analysis of Repetitive wave forms.

Periodic

* A non-sinusoidal wave $f(t)$ repeating with an angular frequency ω can be expressed as:-

$$f(t) = F_0 + \sum_{h=1}^{\infty} f_h(t)$$

$$= \frac{1}{2} a_0 + \sum_{h=1}^{\infty} \left[a_h \cos(h\omega t) + b_h \sin(h\omega t) \right.$$

$F_0 = \frac{1}{2} a_0$ ⇒ average value of $f(t)$

$$a_h = \frac{1}{\pi} \int_0^{2\pi} f(t) \cos(h\omega t)\, d\omega t \quad , \quad h = 0, 1, 2, \ldots, \infty$$

$$b_h = \frac{1}{\pi} \int_0^{2\pi} f(t) \sin(h\omega t)\, d\omega t \quad , \quad h = 1, 2, \ldots, \infty$$

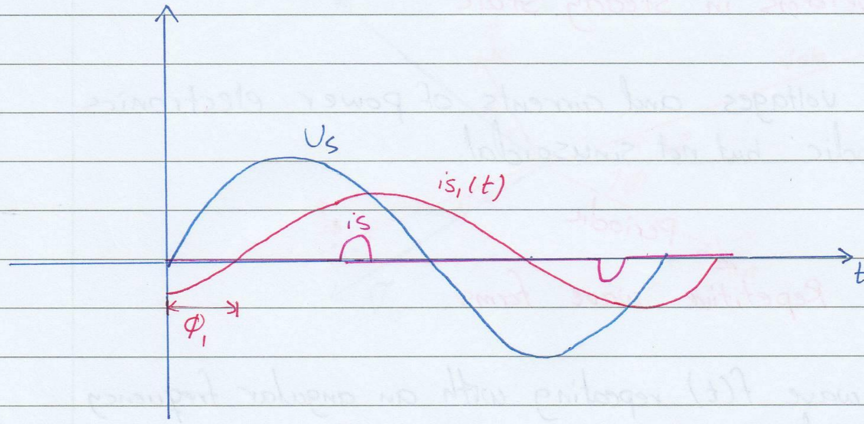
$$F_0 = \frac{1}{2} a_0 = \frac{1}{2} \cdot \frac{1}{\pi} \int_0^{2\pi} f(t)\, d\omega t = \frac{1}{2\pi} \int_0^{2\pi} f(t)\, d\omega t$$

* The RMS value of $f(t)$:-

$$F = \left(F_0^2 + F_1^2 + \ldots + F_\infty^2 \right)^{1/2}$$

$$F = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} (f(t))^2\, d\omega t}$$

- Line Current Distortion



$V_s = \sqrt{2}\, U_s \sin \omega_1 t$

$i_s(t) = i_{s1}(t) + \sum_{h \neq 1}^{\infty} i_{sh}(t)$

$i_{s1}(t)$: fundemental component of $i_s(t)$ ω_1

$i_{sh}(t)$: The component at h harmonic $(f_h = h f_1)$

$$i_s(t) = \sqrt{2}\, I_{s1} \sin(\omega_1 t - \phi_1) + \sum_{h \neq 1}^{\infty} \sqrt{2}\, I_{sh} \sin(\omega_h t - \phi_h)$$

ϕ_1: phase shift between V_s & i_{s1}

$$I_s = \sqrt{\frac{1}{T_1} \int_0^{T_1} (i_s(t))^2 \, dt} \equiv \text{rms value of } i_s(t)$$

$$= \sqrt{I_{s1}^2 + \sum_{h \neq 1}^{\infty} I_{sh}^2}$$

rms Value of the fundemental (fist component)

THD: Total Harmonic Distortion.

$$THD\ \% = \frac{\sqrt{I_s^2 - I_{s_1}^2}}{I_{s_1}} \times 100\ \%$$

$$\int_0^T \sin x \sin 2x\, dx = 0$$

$$\int_0^T \sin x \sin 3x\, dx = 0$$

Power and Power factor.

$$P = \frac{1}{T_1}\int_0^{T_1} V_s(t)\, i_s(t)\, dt = \frac{1}{T_1}\int_0^{T_1} \sqrt{2} V_s \sin\omega_1 t * \Big[\sqrt{2} I_{s_1}\sin(\omega_1 t - \phi_1) + \sum_{h\neq 1}^{\infty} \sqrt{2} I_{sh}\sin(\omega_h t - \phi_h)\Big]dt$$

$$\Rightarrow \quad P = V_s I_{s_1} \cos\phi_1 \quad \Leftarrow$$

The current components at harmonic frequencies do not ~~contripute~~ contribute to the average power of pure sine voltage and not sinusoidal current.

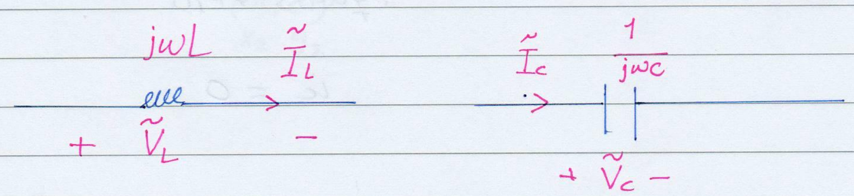
$S = V_s I_s \Rightarrow$ Definition

$$PF = \frac{P}{S} = \frac{V_s I_{s_1} \cos\phi_1}{V_s I_s} = \frac{I_{s_1}}{I_s}\cos\phi_1$$

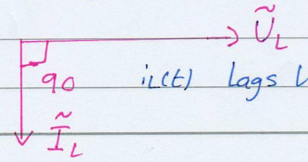
DPF = Displacement PF $= \cos\phi_1$

"Inductor & Capacitor responses"

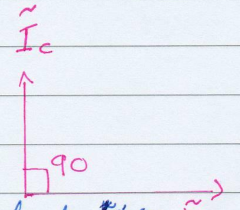
Sinusoidal



$$\tilde{V}_L = j\omega L\, \tilde{I}_L \qquad \tilde{I}_c = j\omega_c \tilde{V}_c$$



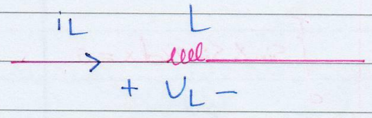
$i_L(t)$ lags $V_L(t)$

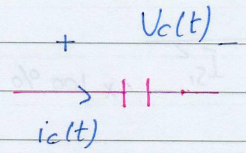


$i_c(t)$ leads $V_c(t)$

Chp3 30_5_2017

Non_Sinusoidal

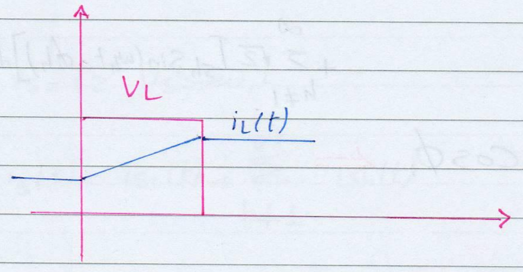


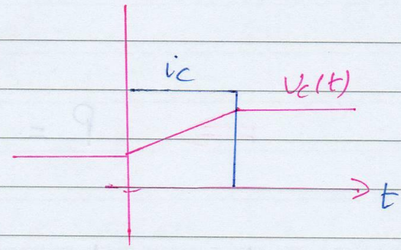


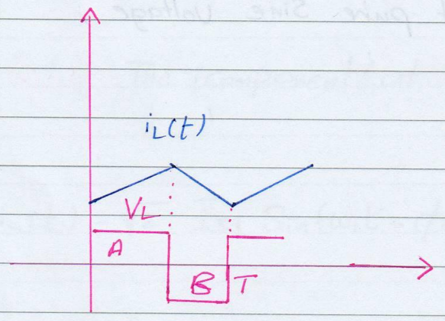
$$V_L(t) = L\frac{di_L(t)}{dt}$$

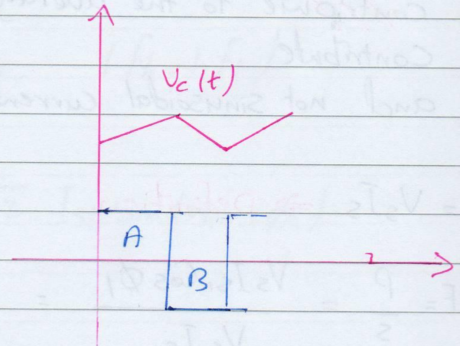
$$i_c(t) = \frac{c\,dv_c(t)}{dt}$$

$$V_c(t) = \frac{1}{C}\int i_c(t)\,dt + K$$









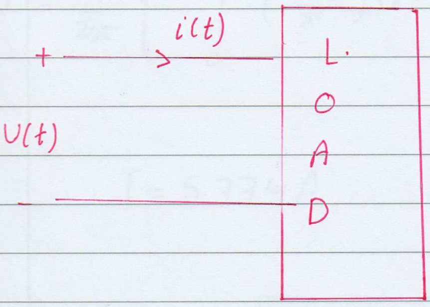
$V_L = 0$

average value of the voltage across the inductance in the steady_state

The average value of the capacitor current in steady_state equals zero

$i_c = 0$

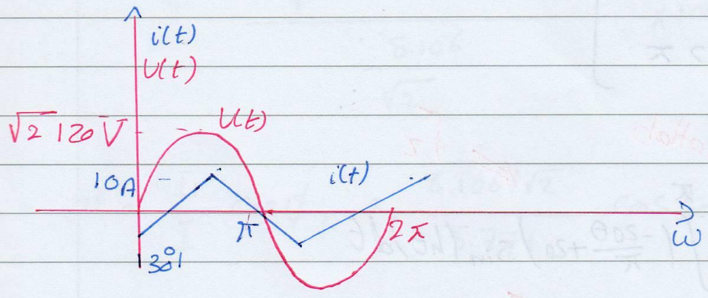
P_3_6 , PP. 58



$v(t) = \sqrt{2}\, V \sin\omega t$, $V = 120$

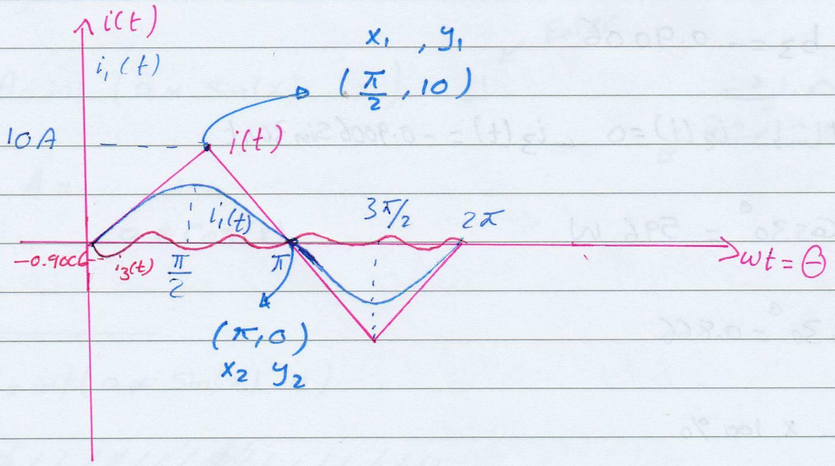
i(t) is a triangular wave with an amplitude of 10A.
also i(t) lags V(t) by 30°

find: P , DPF , THD , PF = ?



_because i(t) is symmetric on the x_axis , all even Components of b_h are zero , also all a_h equals zero:

$p = V I_1 \cos\phi_1 = 120\, I_1 \cos 30^\circ$



$a_h = 0$

$b_h = 0$, for h: even.

$b_1, b_3, b_5, \ldots$

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

$$b_h = \frac{1}{\pi}\int_0^{2\pi} i(\theta)\sin(h\theta)\,d\theta$$

$$i(\theta) = \begin{cases} \frac{20}{\pi}\theta, & 0<\theta<\pi/2 \\ \frac{-20\theta}{\pi}+20, & \frac{\pi}{2}<\theta<3\pi/2 \\ \frac{20\theta}{\pi}-40, & \frac{3\pi}{2}<\theta<2\pi \end{cases}$$

f_1 Matlab $\quad f_2 \quad f_3$

$$b_h = \frac{1}{\pi}\left[\int_0^{\pi/2}\frac{20\theta}{\pi}\sin(h\theta)\,d\theta + \int_{\pi/2}^{\pi}\left(\frac{-20\theta}{\pi}+20\right)\sin(h\theta)\,d\theta + \int_{3\pi/2}^{2\pi}\left(\frac{20\theta}{\pi}-40\right)\sin(h\theta)\,d\theta\right]$$

$b_1 = 8.106$, $b_3 = -0.9006$

$\Rightarrow i_1(t) = 8.106\sin\omega_1 t$, $i_2(t)=0$, $i_3(t) = -0.9006\sin 3\omega_1 t$

$$P = (120)\left(\frac{8.106}{\sqrt{2}}\right)\cos 30^\circ = 596\ W$$

$$DPF = \cos\phi_1 = \cos 30^\circ = 0.866$$

$$THD\% = \frac{\sqrt{I^2 - I_1^2}}{I_1} \times 100\%$$

$$I_1 = \frac{8.106}{\sqrt{2}}\ ,\quad I = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(i(\theta))^2\,d\theta}$$

$$I^2 = \frac{1}{2\pi}\left[\int_0^{\pi/2}\left(\frac{20\theta}{\pi}\right)^2 d\theta + \int_{\pi/2}^{3\pi/2}\left(\frac{-20\theta}{\pi}+20\right)^2 d\theta + \int_{3\pi/2}^{2\pi}\left(\frac{20\theta}{\pi}-40\right)^2 d\theta\right]$$

$I = 5.774A$

$$\therefore \ THD\% = \frac{\sqrt{(5.774)^2 - \left(\frac{8.106}{\sqrt{2}}\right)^2}}{\frac{8.106}{\sqrt{2}}} \times 100\% = 12\%$$

$$PF = \frac{I_1}{I}\cos\phi_1 = \frac{8.106/\sqrt{2}}{5.774}\cos 30^\circ$$

" Symbolic Integration in Matlab "

i.g. $\int a \sin ax = \frac{-a}{a}\cos ax = -\cos ax.$

Ex) write Matlab command to find $\int a \sin x dx$

```
>> syms a x
>> A = int (a * sin(x) , x)    ↵ Enter
```

بعد تنفيذ الأمر هيك
حيطلع عندي عالشاشة

```
A =
   -a * cos(x)
```

```
>> B = int(a * sin(x), a)
```

~~B = 1/2 * a^2 * sin(x)~~

```
B =
   1/2 * a^2 * sin(x)
```

```
>> C=subs(B,a,2)

C =
     2*sin(X)

>> F=a^2*exp(x)

>> R=int(F,x,1,2)

R=
   a^2*exp(2)-a^2*exp(1)

>> M=Vpa(R,5)

M =
     4.6708*a^2
```

back to the previous problem:-

```
>> syms h th

>> F1=((20*th)/pi)*sin(h*th);

>> F2=((-20*th)/pi+20)*sin(h*th);

>> F3= --

>> V1=int(F1,th,0,(pi/2));

   V2=int(F2,th,(pi/2),(3*pi/2));

   V3= --

>> bh=(1/pi)*(V1+V2+V3)
      bh= --
```


>> $b_1 = subs(bh, h, 1)$ ↵

$b_1 = \ldots$

>> $b_2 = subs(bh, h, 2)$

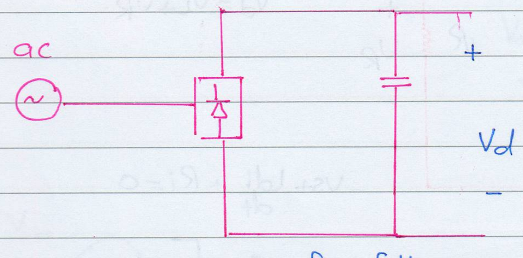
$b_2 =$

$-1.7 \times 10^{-16} \approx 0$

ChP5: Line Frequency Diode Rectifiers: 1-6-2017

Line Frequency ac $\rightarrow$ Uncontrolled dc.

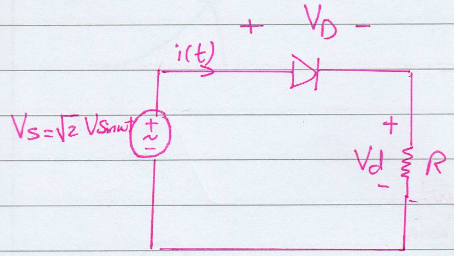
Line frequency $\equiv$ 50 or 60 Hz.

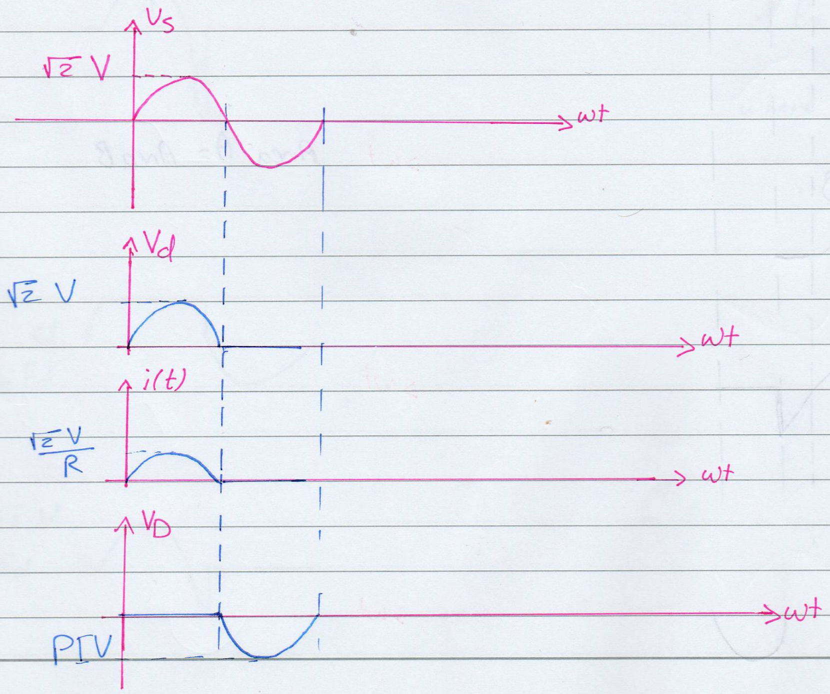


"Block diagram of a rectifier."

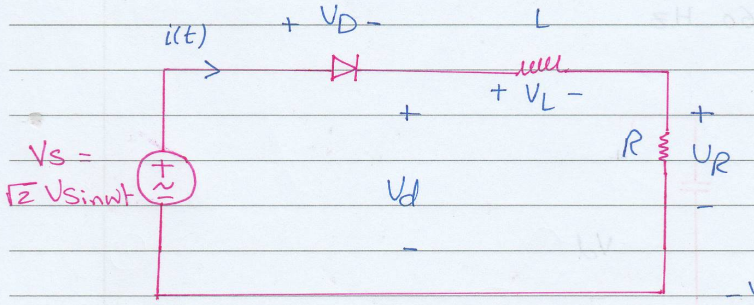
"Basic rectifier Concepts"

1) Half-wave rectifier circuit with pure resistive Load.





2] Half-wave rectifier circuit with inductive load.

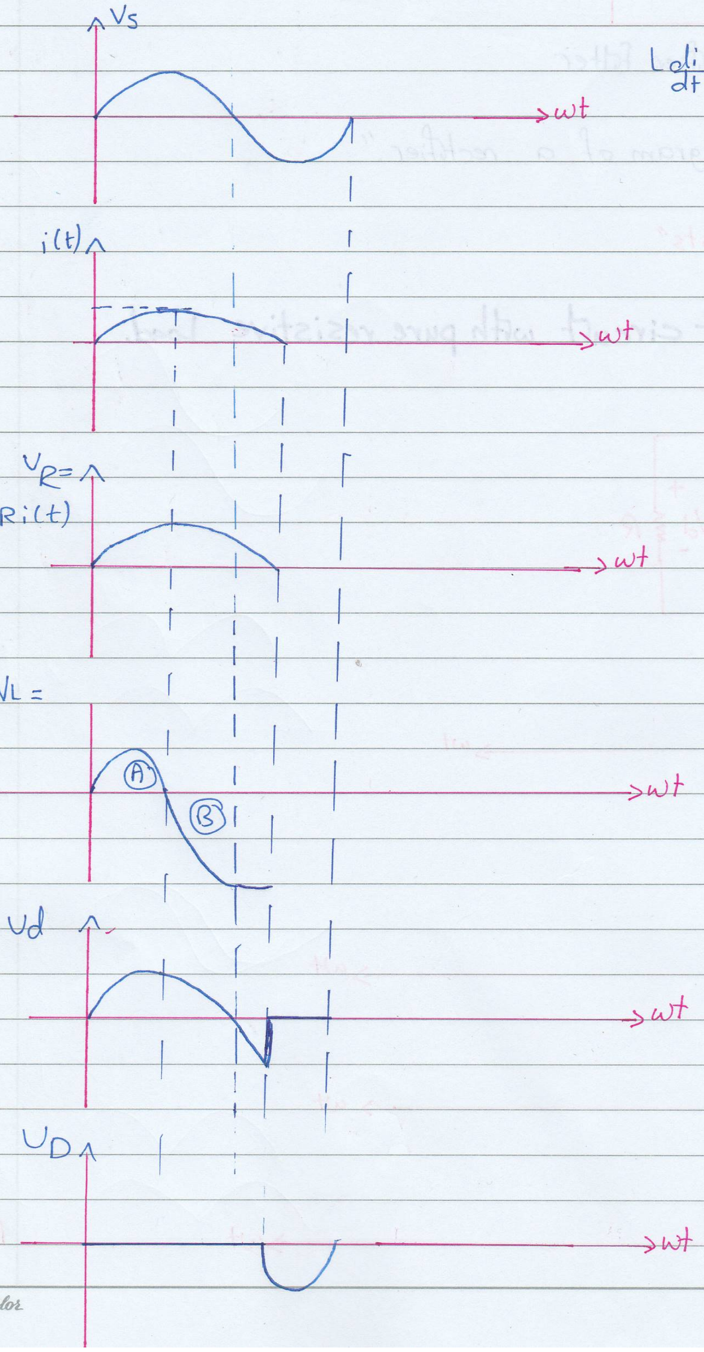


$V_d = V_L + V_R$.

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

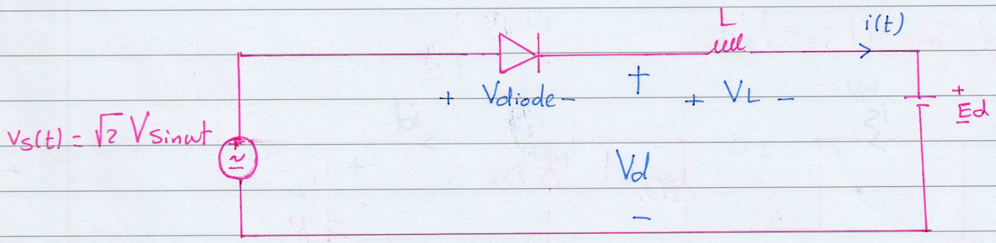
$L\frac{di}{dt} + Ri = \sqrt{2}\, V \sin wt$

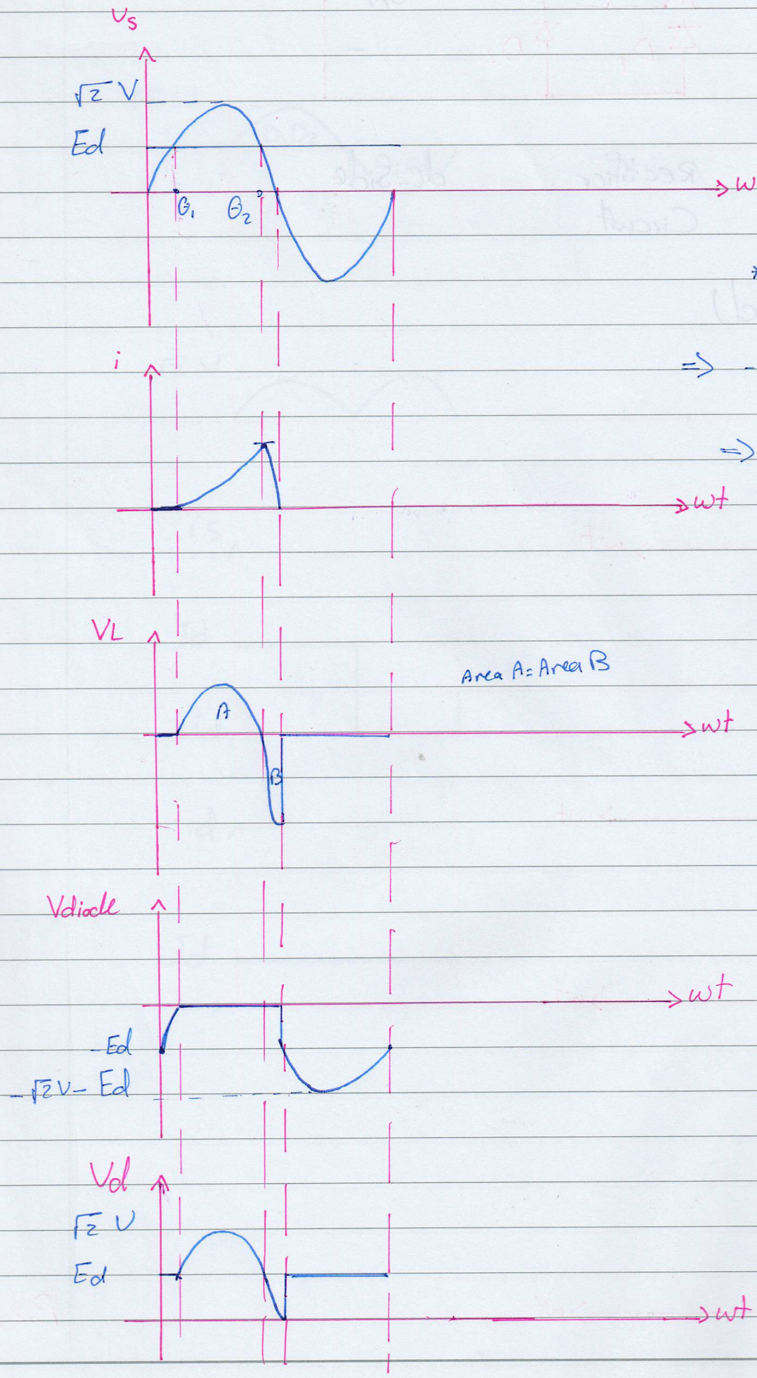
$i(t) = - - -$



Area A = Area B

3) Load with internal dc voltage:





$$* \; L\frac{di}{dt} = \sqrt{2}\,V\sin\omega t - E_d$$

$$\Rightarrow \; -V_s(t) + V_{diode} + E_d = 0$$

$$\Rightarrow \text{ at } \; V_s = E_d$$

$$\sqrt{2}\,V\sin\theta = E_d$$

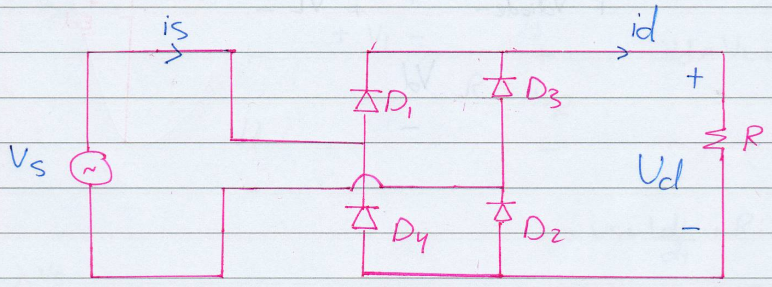
$$\theta_1 = \sin^{-1}\left[\frac{E_d}{\sqrt{2}\,V}\right]$$

$$\& \; \theta_2 = \pi - \theta_1$$

where $\theta = \omega t$.

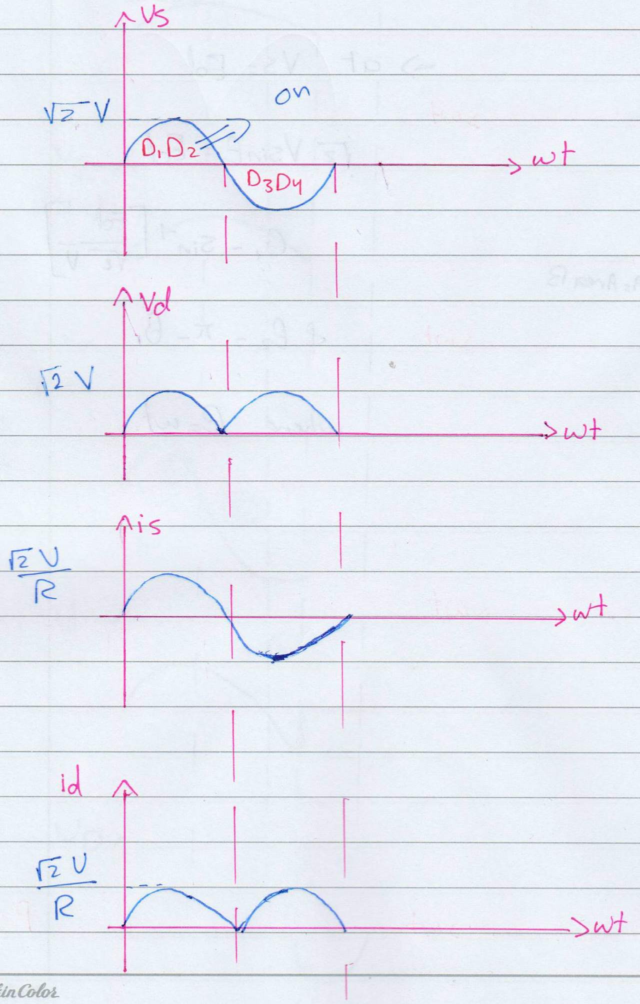
"Single-Phase Diode Bridge Rectifiers"

1] Idealized Case ($L_s = 0$)

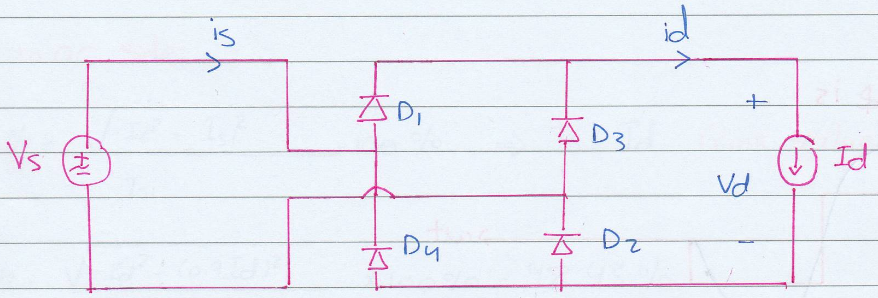


ac-Side Rectifier Circuit dc-Side

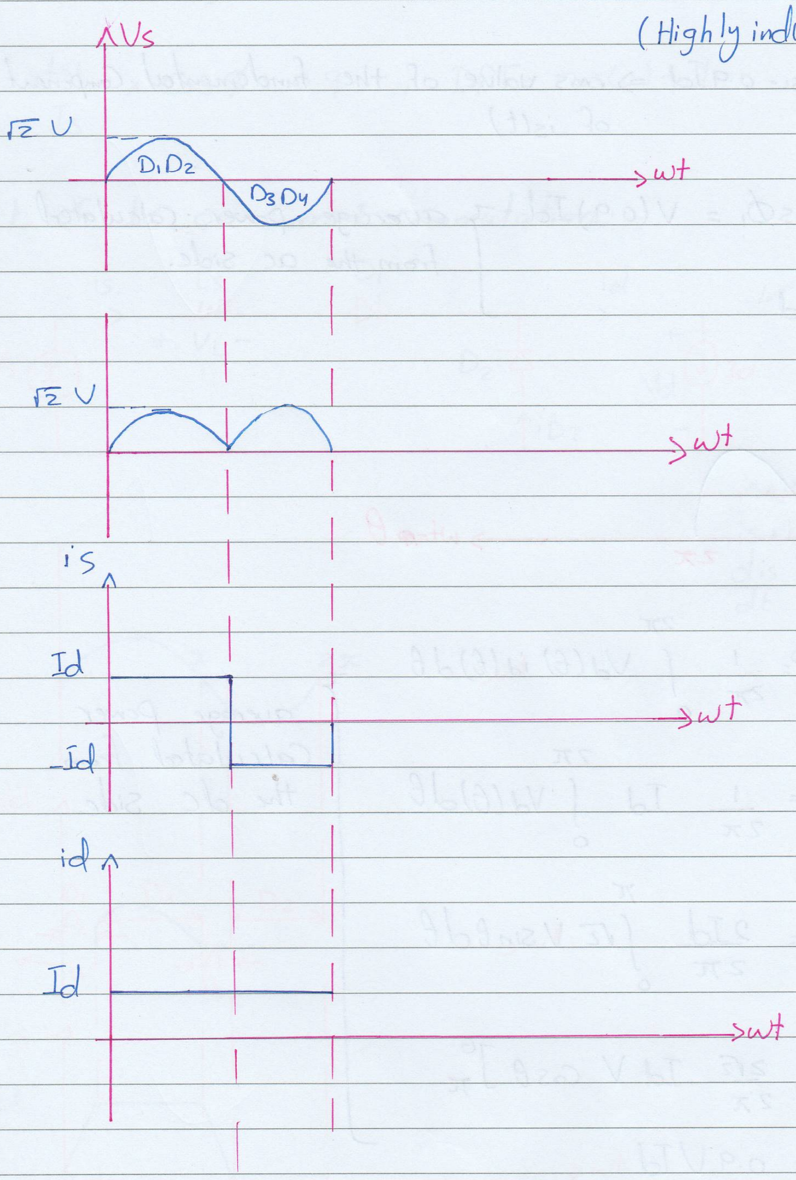
(Pure Resistive Load)

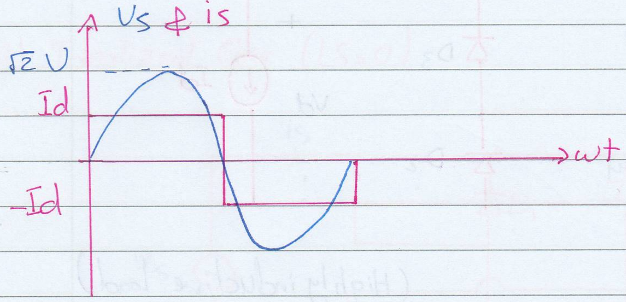


4-6-2017



(Highly inductive load)



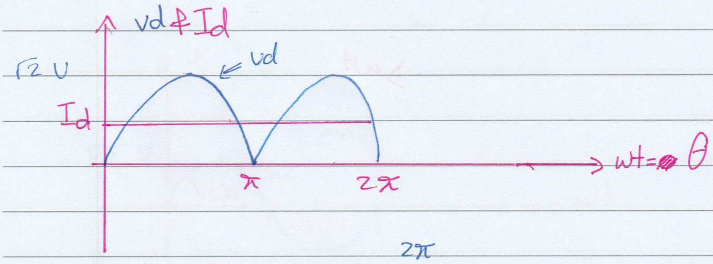


$I_{s1} = 0.9 I_d \Rightarrow$ rms value of the fundemental Component of is(t)

$$P = V I_{s1} \cos\phi_1 = V(0.9) I_d$$

$$P = 0.9 V I_d$$

average power calculated from the ac side.



$$P = \frac{1}{2\pi} \int_0^{2\pi} V_d(\theta)\, i_d(\theta)\, d\theta$$

$$= \frac{1}{2\pi} I_d \int_0^{2\pi} V_d(\theta)\, d\theta$$

$$= \frac{2 I_d}{2\pi} \int_0^{\pi} \sqrt{2} V \sin\theta\, d\theta$$

$$= \frac{2\sqrt{2}}{2\pi} \cdot I_d V \cos\theta \Big]_{\pi}^{0}$$

$$P = 0.9 V I_d$$

average power Calculated from the dc side.

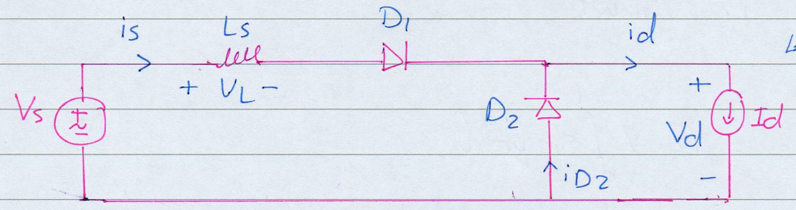
. Back to ac side:-

$$THD\% = \frac{\sqrt{I_s^2 - I_{s1}^2}}{I_{s1}} \times 100\% \Rightarrow I_s = I_d \quad (\text{rms value})$$

$$THD\% = \frac{\sqrt{I_d^2 - (0.9 I_d)^2}}{0.9\, I_d} \times 100\% = 48.43\%$$

$$PF = \frac{I_{s1}}{I_s} \times \cos\phi = 0.9 \quad , \quad DPF = \cos(0) = 1$$

2) Effect of L_s on current commutation.

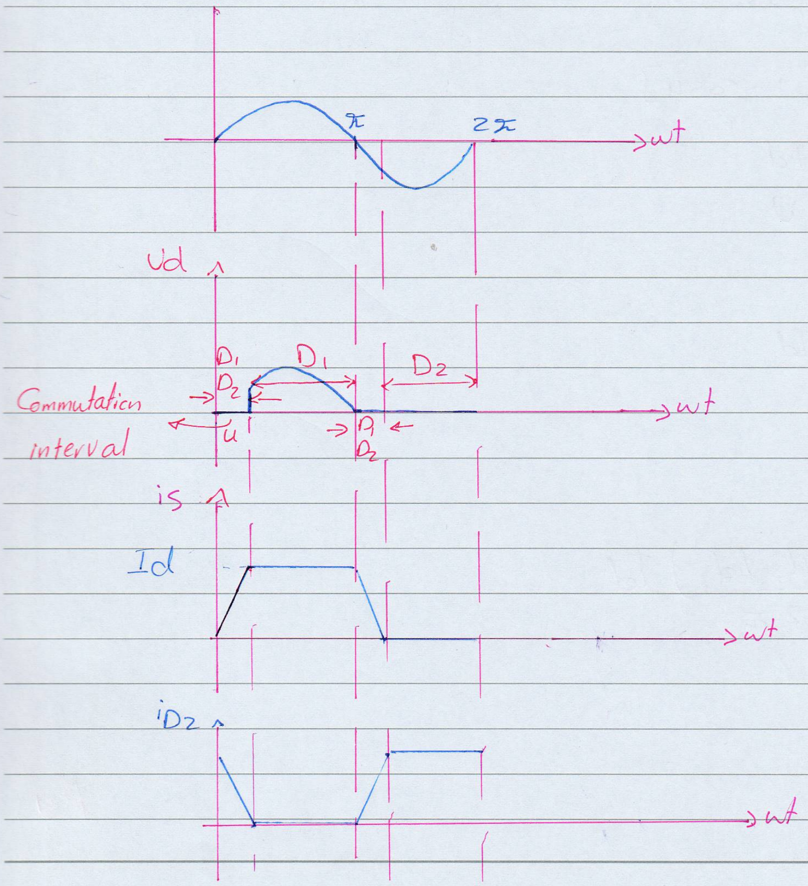


Half_wave Rectifier

$$-i_s - i_{D2} + I_d = 0$$

$$i_s + i_{D2} = I_d$$

$$\frac{di_s}{dt} = \frac{-di_{D2}}{dt}$$



$$V_d = \frac{1}{2\pi}\int_0^{2\pi} v_d(\theta)\,d\theta = \frac{1}{2\pi}\int_u^{\pi} \sqrt{2}\,V\sin\theta\,d\theta$$

$$V_d = \frac{\sqrt{2}\,V}{2\pi}\left[\cos u + 1\right]$$

During Commutation.

$$V_L = V_s$$

$$L_s \frac{di_s}{dt} = \sqrt{2}\,V\sin\omega t$$

$$\omega L_s \frac{di_s}{d\omega t} = \sqrt{2}\,V\sin\omega t$$

$$\omega L_s \int_0^{I_d} di_s = \sqrt{2}\,V\int_0^{u}\sin\theta\,d\theta$$

$$\omega L_s I_d = \sqrt{2}\,V\cos\theta\Big]_u^0$$

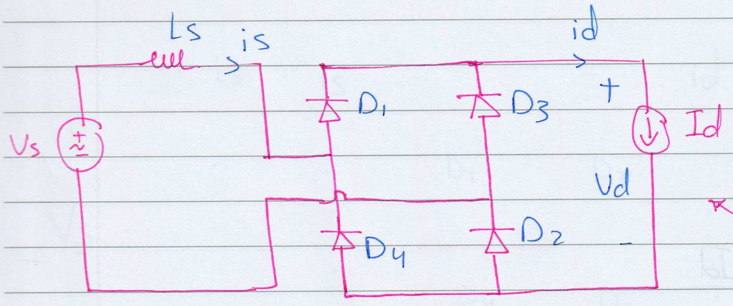
$$\omega L_s I_d = \sqrt{2}\,V\left[1-\cos u\right]$$

$$\cos u = 1 - \frac{\omega L_s I_d}{\sqrt{2}\,V} \Rightarrow u =$$

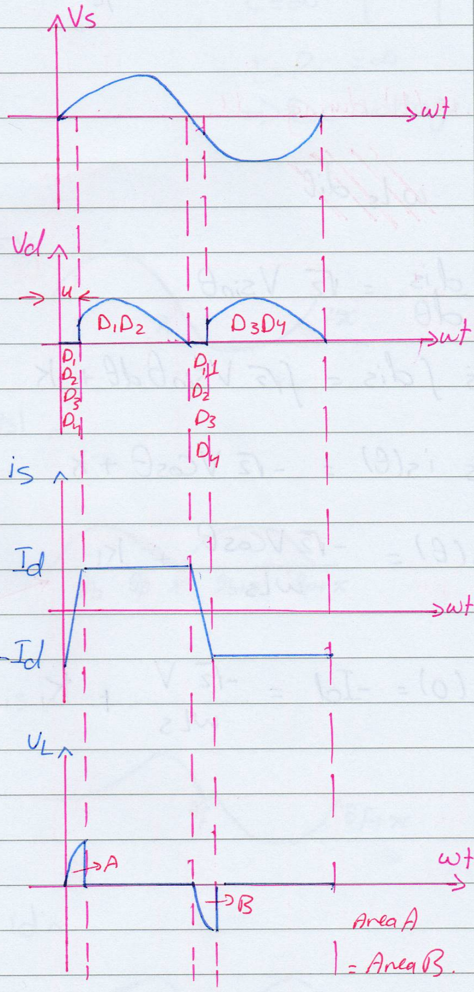
$$V_d = 0.45V - \frac{\omega L_s I_d}{2\pi}$$

$$P_d = V_d I_d$$

$$\Rightarrow P_d = \left(0.45V - \frac{\omega L_s I_d}{2\pi}\right) I_d.$$



⇐ Full wave Bridge rectifier with constant Current.



Effects:-

1) Commutation interval with all diodes are on in it and $V_d = 0$

2) Reduce average power and voltage.

average voltage

$$V_d = \frac{1}{2\pi}\int_0^{2\pi} V_d(\theta)\, d\theta$$

$$V_d = \frac{1}{2\pi} \times 2 \int_{\cancel{0}\,u}^{\pi} \sqrt{2}\, V \sin\theta\, d\theta$$

$$= \frac{\sqrt{2}\,V}{\pi} \cos\theta \Big]_{\pi}^{u}$$

$$= \frac{\sqrt{2}\,V}{\pi} (\cos u + 1)$$

. During Commutation:-

$V_L = V_s$

$L_s \frac{di_s}{dt} = \sqrt{2}\, V \sin\omega t$

$\omega L_s \frac{di_s}{d\omega t} = \sqrt{2}\, V \sin\omega t$

$\omega L_s \frac{di_s}{dt} = \sqrt{2}\, V \sin\theta$

$\omega L_s \int_{-I_d}^{I_d} di_s = \int_0^{u} \sqrt{2}\, V \sin\theta\, d\theta$

$2\omega L_s I_d = \sqrt{2}\, V \cos\theta \Big]_u^0$

$$2\omega L_s I_d = \sqrt{2}\, V[1-\cos u]$$

$$\cos u = 1 - \frac{2\omega l_s I_d}{\sqrt{2}\, V}$$

$$\therefore\ V_d = 0.9V - \frac{2\omega l_s I_d}{\pi}$$

. $i_s(t)$ during u.

~~$\omega l_s\, di$~~

$$\omega l_s \frac{d i_s}{d\theta} = \sqrt{2}\, V\sin\theta$$

$$\omega L_s \int d i_s = \int \sqrt{2}\, V\sin\theta\, d\theta + K$$

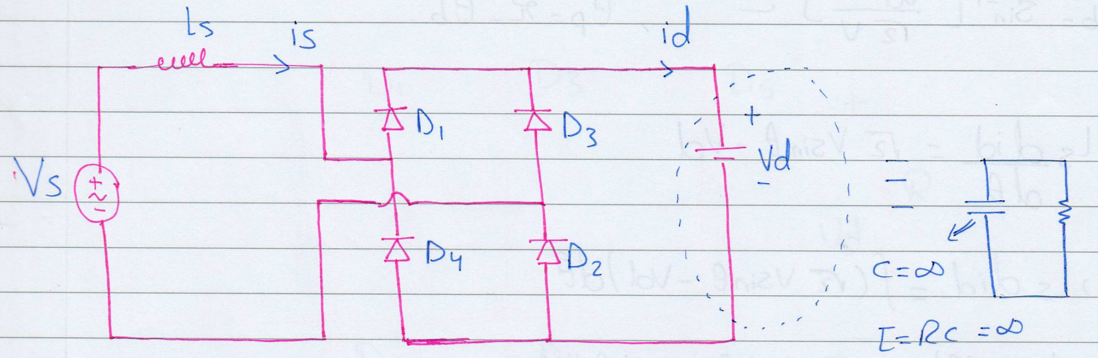
$$\omega L_s\, i_s(\theta) = -\sqrt{2}\, V\cos\theta + k$$

$$i_s(\theta) = \frac{-\sqrt{2}\, V\cos\theta}{\omega l_s} + K_1$$

$$i_s(0) = -I_d = \frac{-\sqrt{2}\, V}{\omega L_s} + K_1 \quad , \quad K_1 =$$

Ch5 5-6-2017

Constant dc-Side voltage $\Rightarrow V_d(t) = V_d$



$E = RC = \infty$
$\Rightarrow$ Dc voltage

at:

$V_d = V_s$

$V_d = \sqrt{2} V \sin\theta_b$

$\theta_b = \sin^{-1}\left[\frac{V_d}{\sqrt{2} V}\right]$

$\theta_p = \pi - \theta_b$

$\theta_f \geq \theta_p$

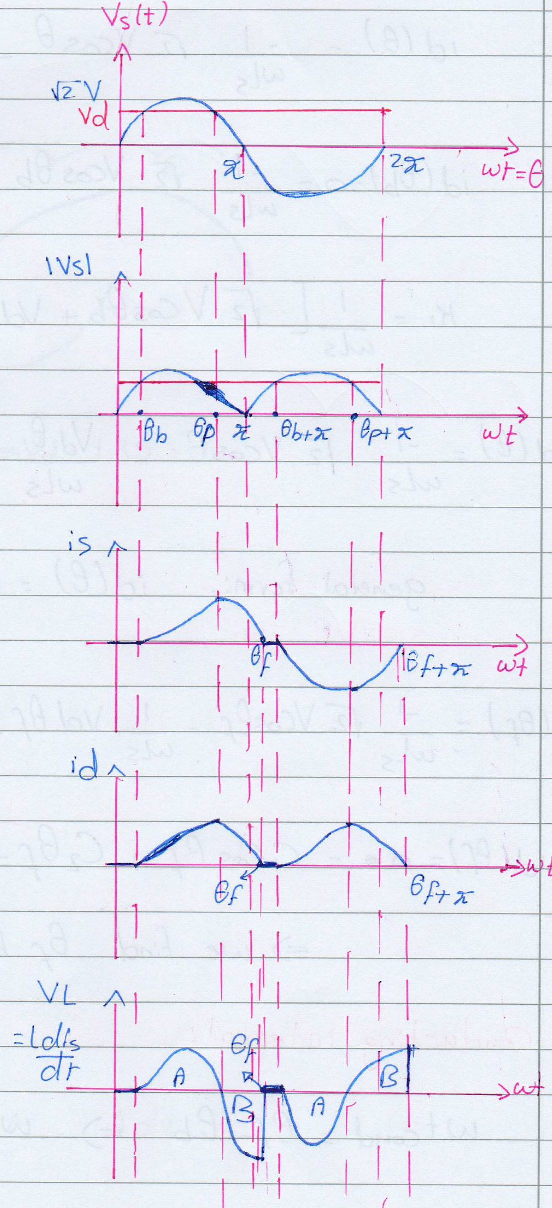
$\Rightarrow -V_s + L_s \frac{di_s}{dt} + V_d = 0$

$L_s \frac{di_s}{dt} = V_s - V_d$

$\omega L_s \frac{di_s}{d\omega t} = \sqrt{2} V \sin\omega t - V_d$

$I_d = \frac{1}{2\pi} \int_0^{2\pi} i_d(\theta)\, d\theta$

$= \frac{2}{2\pi} \int_{\theta_b}^{\theta_f} i_d(\theta)\, d\theta$



$\theta_b = \sin^{-1}\left[\frac{V_d}{\sqrt{2}\,V}\right]$, $\theta_p = \pi - \theta_b$.

$$\omega L_s \frac{d\,i_d}{d\theta} = \sqrt{2}\,V\sin\theta - V_d$$

$$\int \omega L_s\, d i_d = \int (\sqrt{2}\,V\sin\theta - V_d)\,d\theta$$

$$\omega L_s\, i_d(\theta) = -\sqrt{2}\,V\cos\theta - V_d\,\theta + k$$

$$i_d(\theta) = \frac{-1}{\omega L_s}\sqrt{2}\,V\cos\theta - \frac{V_d\theta}{\omega L_s} + k_1$$

$$i_d(\theta_b) = 0 = \frac{-1}{\omega L_s}\sqrt{2}\,V\cos\theta_b - \frac{V_d\theta_b}{\omega L_s} + k_1$$

$$k_1 = \frac{1}{\omega L_s}\left[\sqrt{2}\,V\cos\theta_b + V_d\theta_b\right]$$

$$i_d(\theta) = \frac{-1}{\omega L_s}\sqrt{2}\,V\cos\theta - \frac{V_d\theta}{\omega L_s} + \frac{1}{\omega L_s}\sqrt{2}\,V\cos\theta_b + \frac{1}{\omega L_s}V_d\theta_b$$

general form:- $i_d(\theta) = C_1\cos\theta + C_2\theta + C_3$

$$i_d(\theta_f) = \frac{-1}{\omega L_s}\sqrt{2}\,V\cos\theta_f - \frac{1}{\omega L_s}V_d\theta_f + \frac{1}{\omega L_s}\sqrt{2}\,V\cos\theta_b + \frac{1}{\omega L_s}V_d\theta_b$$

$$i_d(\theta_f) = 0 = C_1\cos\theta_f + C_2\overset{\text{radian}}{\theta_f} + C_3$$

$\Rightarrow$ we find θ_f by Trial and error.

$\Rightarrow$ Conducting interval:-

$\omega t_{cond} = \theta_f - \theta_b \Rightarrow \omega = 2\pi f$.

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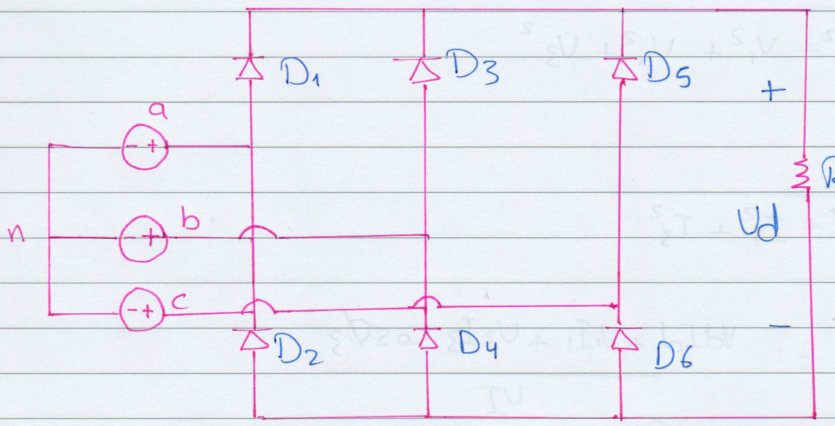
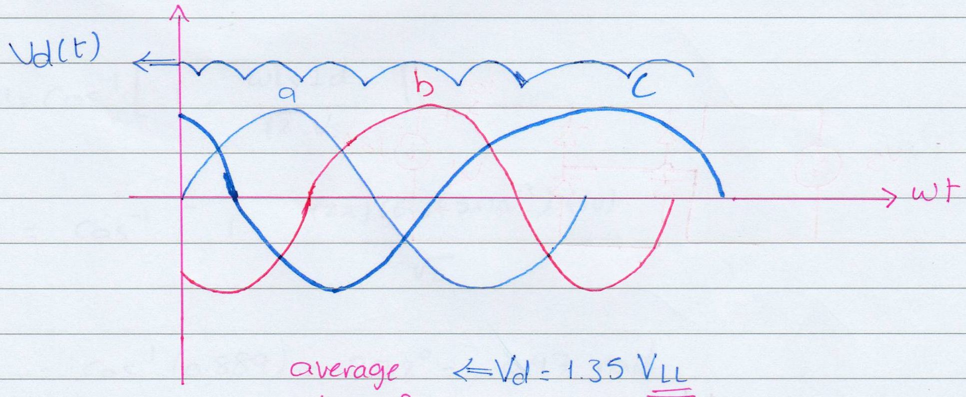
Chp5 6-6-2017

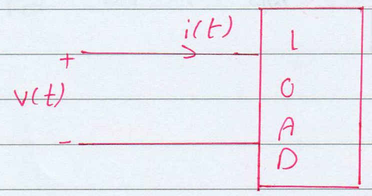




average value of the o/p voltage $\Leftarrow V_d = 1.35\, V_{LL}$

rms value of the three phase line voltage.

P 5.3



$v(t) = V_d + \sqrt{2}\, V_1 \cos w_1 t + \sqrt{2}\, V_1 \sin w_1 t$

$+ \sqrt{2}\, V_3 \cos(w_3 t)$ Volts

$i(t) = I_d + \sqrt{2}\, I_1 \cos w_1 t + \sqrt{2} I_3 \cos(w_3 t - \phi_3)$ A

a) $P = \frac{1}{T}\int_0^T v(t)\, i(t)\, dt = \frac{1}{T}\int_0^T (\quad)*(\quad)\, dt$

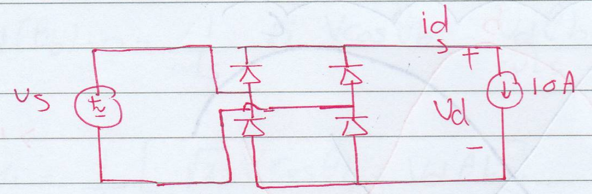
$= V_d I_d + V_1 I_1 + V_3 I_3 \cos\phi_3$

b) $V = \sqrt{V_d^2 + V_1^2 + V_1^2 + V_3^2}$

$I = \sqrt{I_d^2 + I_1^2 + I_3^2}$

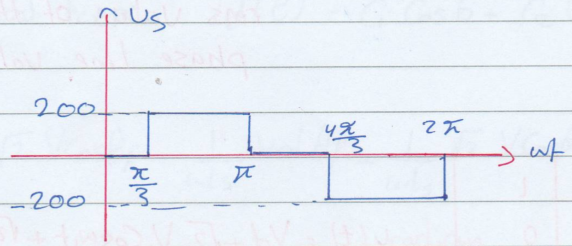
c) $PF = \dfrac{P}{S} = \dfrac{V_d I_d + V_1 I_1 + V_3 I_3 \cos\phi_3}{VI}$

5-4)

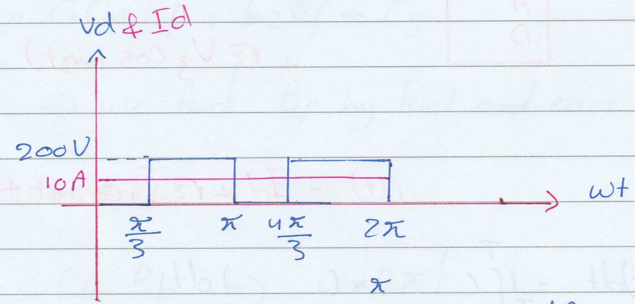


a) if Vs is sinusoidal

b) if Vs is



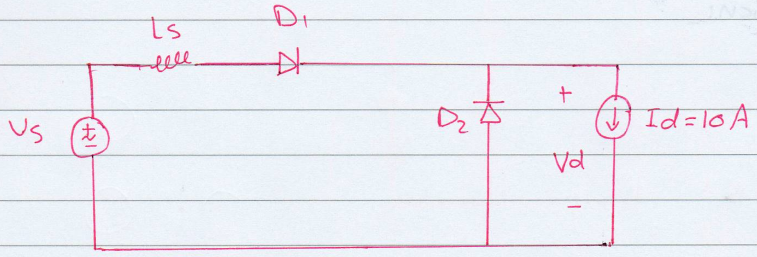
$P = ?$



$P = \dfrac{1}{2\pi}\int_0^{2\pi} v_d(\theta)\, i_d(\theta)\, d\theta = \dfrac{1}{\pi}\int_{\pi/3}^{\pi} (200)(10)\, d\theta = \dfrac{1}{\pi}\left(2000\,\dfrac{2\pi}{3}\right)$

$= \dfrac{4000}{3}$ W

5.5)



$L_s = 5mH$, $f = 60\,Hz$, $V_s = 120\,V$

P_d, V_d, $u = ?$

⇐ نفس رسمات ال Half wave

$$u = \cos^{-1}\left[1 - \frac{\omega L_s I_d}{\sqrt{2}\,V_s}\right]$$

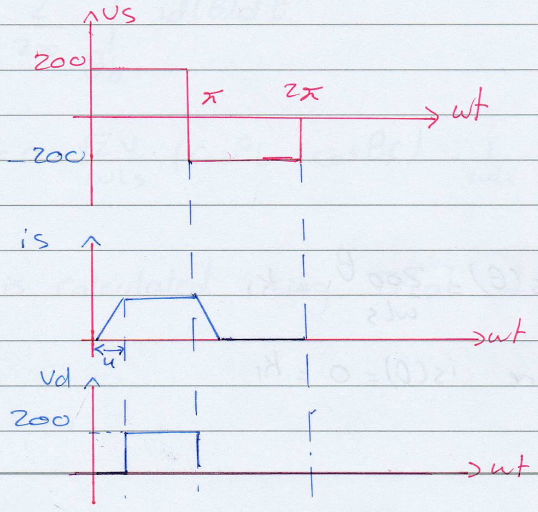
$$= \cos^{-1}\left[1 - \frac{(2\pi)(60)(5\times10^{-3})(10)}{\sqrt{2}}\right]$$

$$= \cos^{-1}(0.889) = 27.2^\circ = 0.47\text{ rad.}$$

$$V_d = 0.45\,V_s - \frac{\omega L_s I_d}{2\pi} = 54 - 3 = 51\,V$$

$$P_d = V_d I_d = (51)(10) = 510\,W$$

c)



During commutation:-

$V_L = V_s$

$L_s \frac{di_s}{dt} = 200$

$\omega L_s \frac{di_s}{d\omega t} = 200$

$\omega L_s \int_0^{10} di_s = 200 \int_0^{u} d\omega t$

$\omega L_s (10) = 200 u \Rightarrow u = \frac{\omega L_s (10)}{200} = 0.094 \text{ rad} = 5.4°$

$V_d = \frac{1}{2\pi} \int_u^{\pi} 200 \, d\theta$

$= \frac{200}{2\pi} [\pi - u]$

$= \frac{200}{2\pi} [\pi - 0.094] = 97 \text{ V}$

$P_d = V_d I_d = 97(10) = 970 \text{ W}$

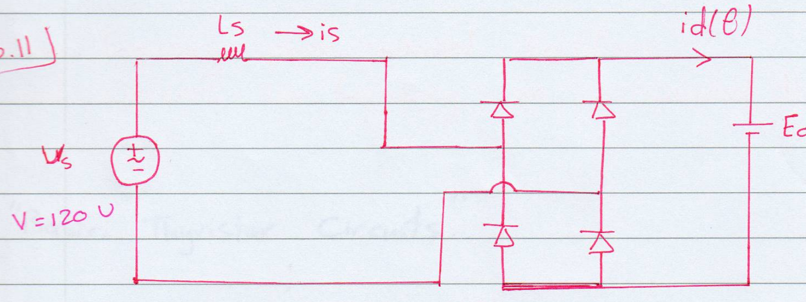
$i_s(\theta)$ due commutation:-

$\omega L_s di_s = 200 d\omega t$

$\omega L_s i_s(\theta) = 200\theta + K \Rightarrow i_s(\theta) = \frac{200\theta}{\omega L_s} + K_1$

where $i_s(0) = 0 = K_1$

5.11)

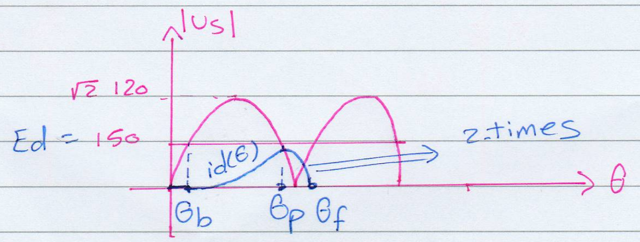


$f_s = 60\ Hz$

$L = 1\ mH$

$E_d = 150\ V$

⇒



$$\theta_b = \sin^{-1}\left(\frac{150}{\sqrt{2}\,120}\right) = 1.0841\ \text{rad} = 62.1144^\circ$$

$$\theta_p = \pi - \theta_b = 180 - 62.1144 = 117.886^\circ = 2.058\ \text{rad}.$$

$$i_d(\theta) = \frac{\sqrt{2}\,V}{\omega L_s}(\cos\theta_b - \cos\theta) - \frac{1}{\omega L_s} V_d\theta + \frac{1}{\omega L_s} V_d\theta_b$$

$$i_d\Big|_{Peak} = i_d\Big|_{\theta=\theta_p} = \frac{\sqrt{2}\,V}{\omega L_s}(\cos\theta_b - \cos\theta_p) - \frac{1}{\omega L_s} V_d\theta_p + \frac{1}{\omega L_s} V_d\theta_b$$

[rad]

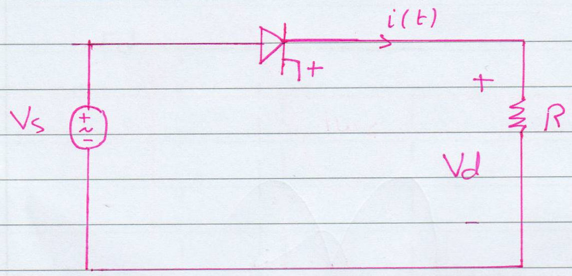
$$I_d = \frac{2}{2\pi}\int_{\theta_b}^{\theta_f} i_d(\theta)\,d\theta$$

$$i_d(\theta_f) = 0 = \frac{\sqrt{2}\,V}{\omega L_s}(\cos\theta_b - \cos\theta_f) - \frac{1}{\omega L_s} V_d\theta_f + \frac{1}{\omega L_s} V_d\theta_f$$

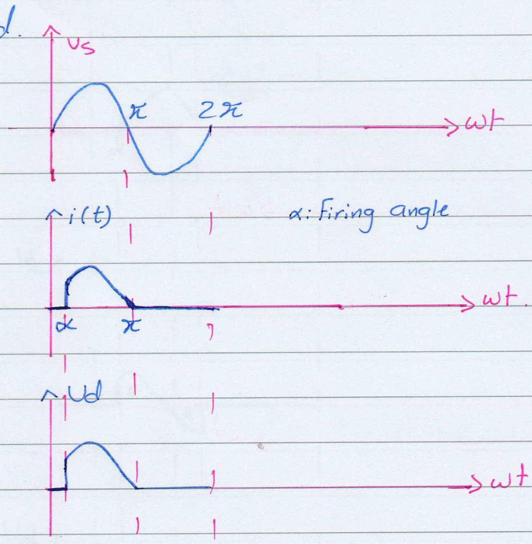
⇒ θ_f is calculated using Trial & Error.

"Line frequency phase-Controlled Rectifiers.
and inverters: Line-frequency ac → controlled dc.

"Basic Thyristor Circuits."



Half_wave controlled rectifier circuit with pure resistive Load.

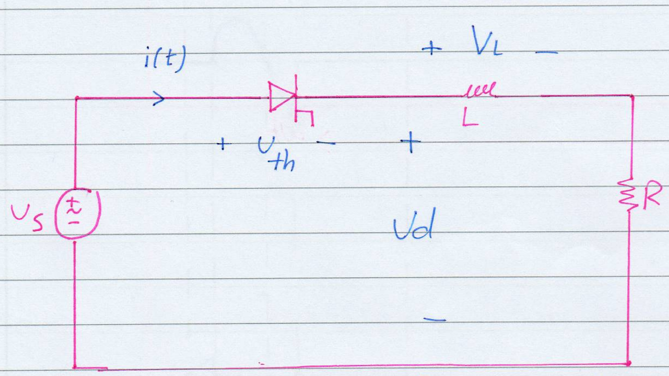


$$V_d = \frac{1}{2\pi}\int_{\alpha}^{\pi} \sqrt{2}\, V \sin\omega t \, d\omega t$$

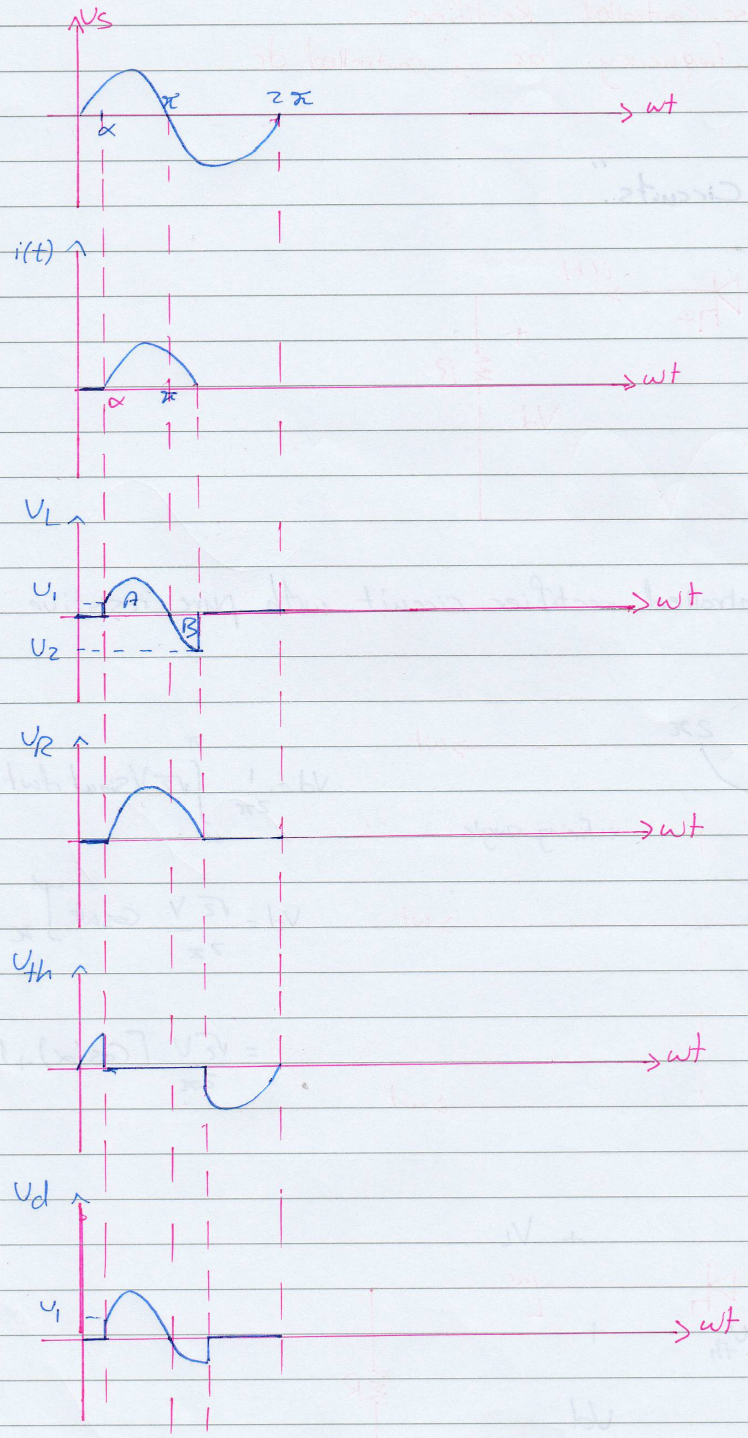
$$V_d = \frac{\sqrt{2}\, V}{2\pi} \cos\omega t \Big]_{\pi}^{\alpha}$$

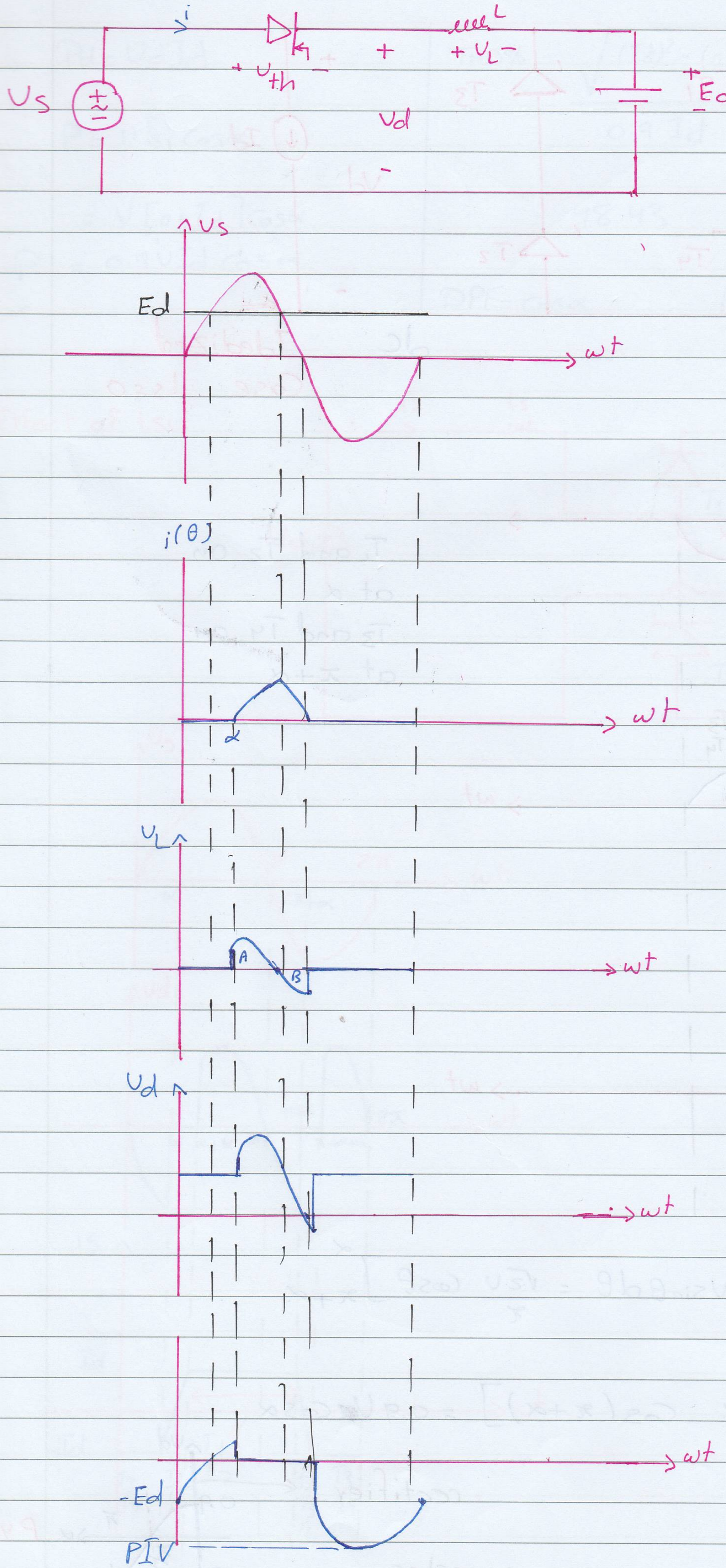
$$= \frac{\sqrt{2}\, V}{2\pi}\left[\cos(\alpha) + 1\right]$$

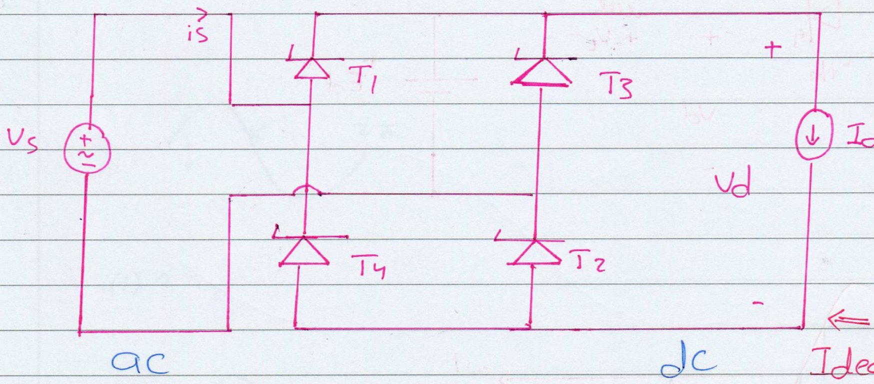
⇒



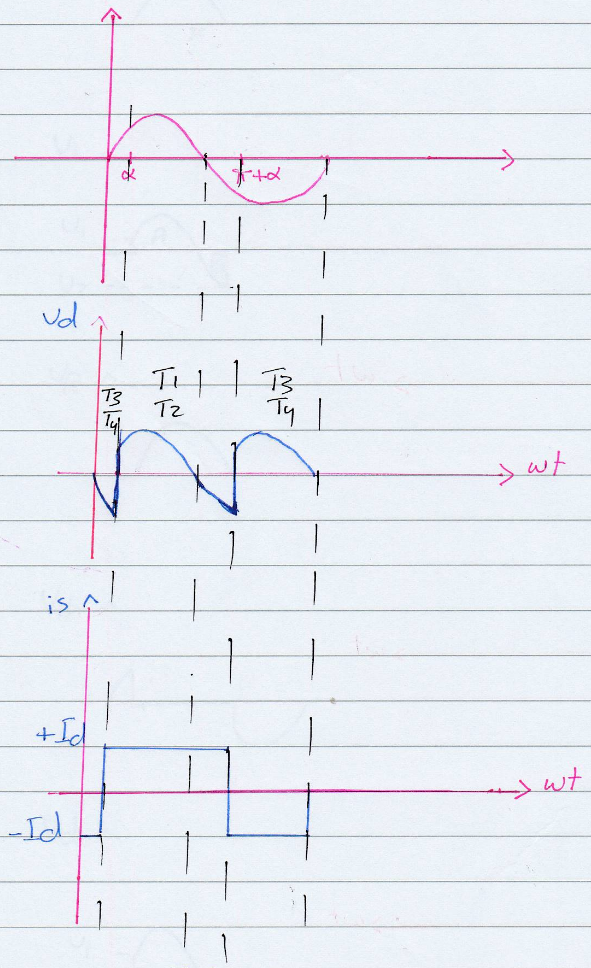
Half_wave controlled rectifier circuit with inductive load.


Vs
wt
α
π
2π
i(t)
VL
V1
A
B
V2
VR
Vth
Vd


i
L
+ v_{th} −
+
+ V_L −
V_s
+ Ed −
V_d
−
V_s
Ed
wt
$i(\theta)$
α
wt
V_L
A
B
wt
V_d
wt
wt
-Ed
PIV



Idealized Case $L_s = 0$

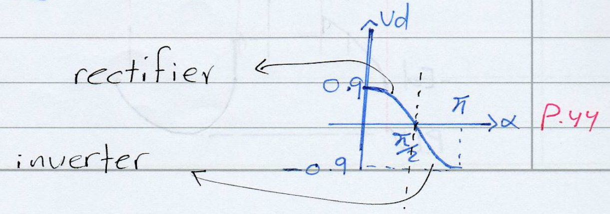


T_1 and T_2 on at α

T_3 and T_4 on at $\pi+\alpha$

$$V_d = \frac{2}{2\pi}\int_{\alpha}^{\pi+\alpha} \sqrt{2}\, V \sin\theta \, d\theta = \frac{\sqrt{2}V}{\pi} \cos\theta \Big]_{\pi+\alpha}^{\alpha}$$

$$= \frac{\sqrt{2}V}{\pi}\left[\cos\alpha - \cos(\pi+\alpha)\right] = 0.9\, V \cos\alpha$$



P.44

$P_d = U_d I_d$

$P = U I_{s1} \cos\alpha$

$= V[0.9 I_d] \cos\alpha$

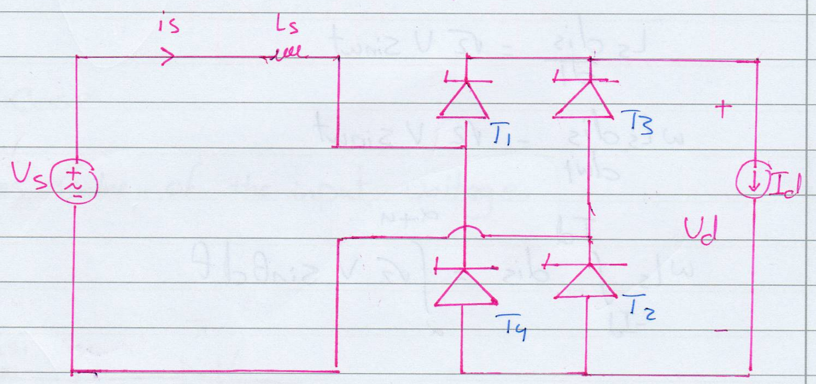
$P = 0.9 V I_d \cos\alpha$

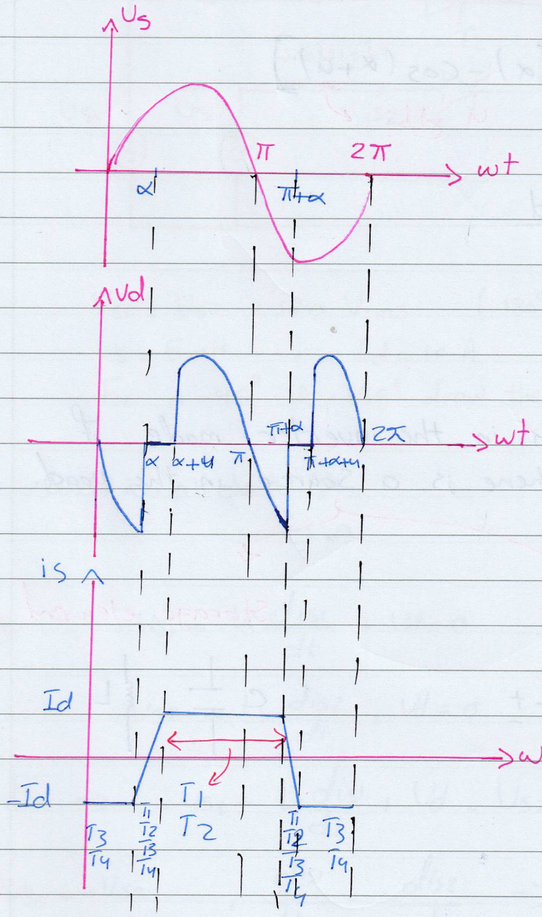
$$THD\% = \frac{\sqrt{(I_d)^2 - (0.9 I_d)^2}}{0.9 I_d} \times 100\%$$

$= 48.43$

$DPF = \cos\alpha$, $PF = 0.9 \cos\alpha$

Effect of L_s:-





$$V_d = \frac{2}{2\pi}\int_{\alpha+u}^{\alpha+\pi} \sqrt{2}V\sin\theta\, d\theta = \frac{\sqrt{2}V}{\pi}\cos\theta\Big]_{\alpha+\pi}^{\alpha+u}$$

$$= \frac{\sqrt{2}V}{\pi}\left[\cos(\alpha+u) - \cos(\alpha+\pi)\right]$$

During Commutation:-

$$V_L = V_s$$

$$L_s\frac{di_s}{dt} = \sqrt{2}\,V\sin\omega t$$

$$\omega L_s\frac{di_s}{d\omega t} = \sqrt{2}\,V\sin\omega t$$

$$\omega L_s\int_{-I_d}^{I_d} di_s = \int_{\alpha}^{\alpha+u}\sqrt{2}\,V\sin\theta\, d\theta$$

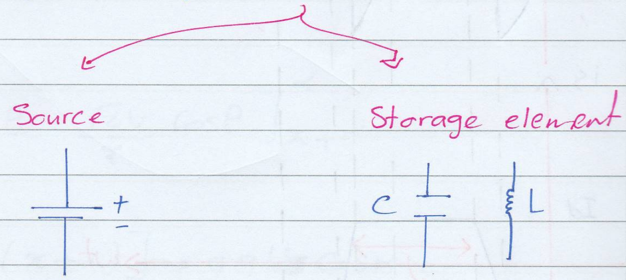
$$2\omega L_s I_d = \sqrt{2}V\left[\cos(\alpha) - \cos(\alpha+u)\right]$$

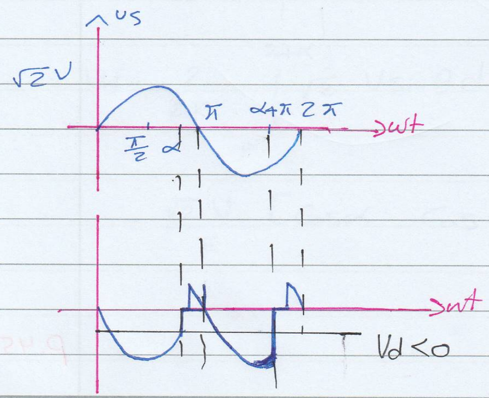
بطلع u

$$V_d = 0.9V\cos\alpha - \frac{2\omega L_s I_d}{\pi}$$

→ Inverter Mode of Operation:-

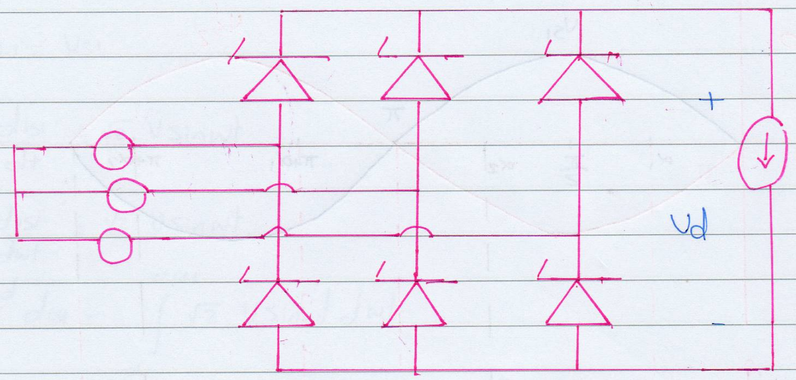
Controlled Rectifier ccts can run in the inverter mode if α is greater than 90° and there is a Source in the Load.





Chp6 13-6-2017

"Three-phase Converter"

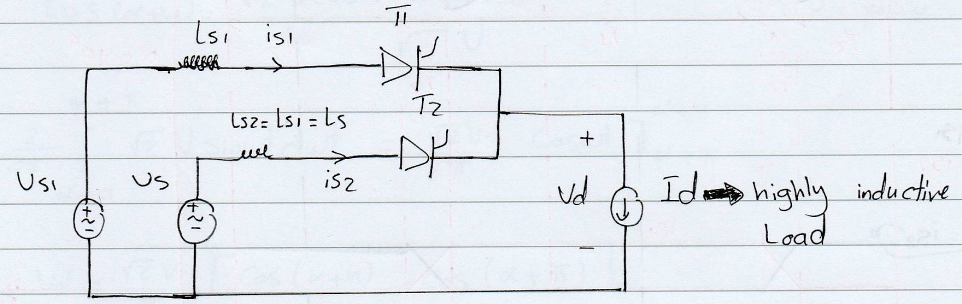


$V_d = 1.35 V_{LL} \cos\alpha$

Line-Line rms value of the input voltage.

"Problems"

6-1)



$V_{s1} = V_{s2} = 120\ V_{rms}$. (180° out of phase)

$L_s = 5mH$, $I_d = 10\ A$, 60 HZ

For $\alpha = 45°$ & 135° draw the wave forms

⇒ الرسمة على الصفحة اللي بعد هاي

$$\Rightarrow \quad -V_{s1} + L_s \frac{di_{s1}}{dt} + V_d = 0 \quad \text{-- } (1)$$

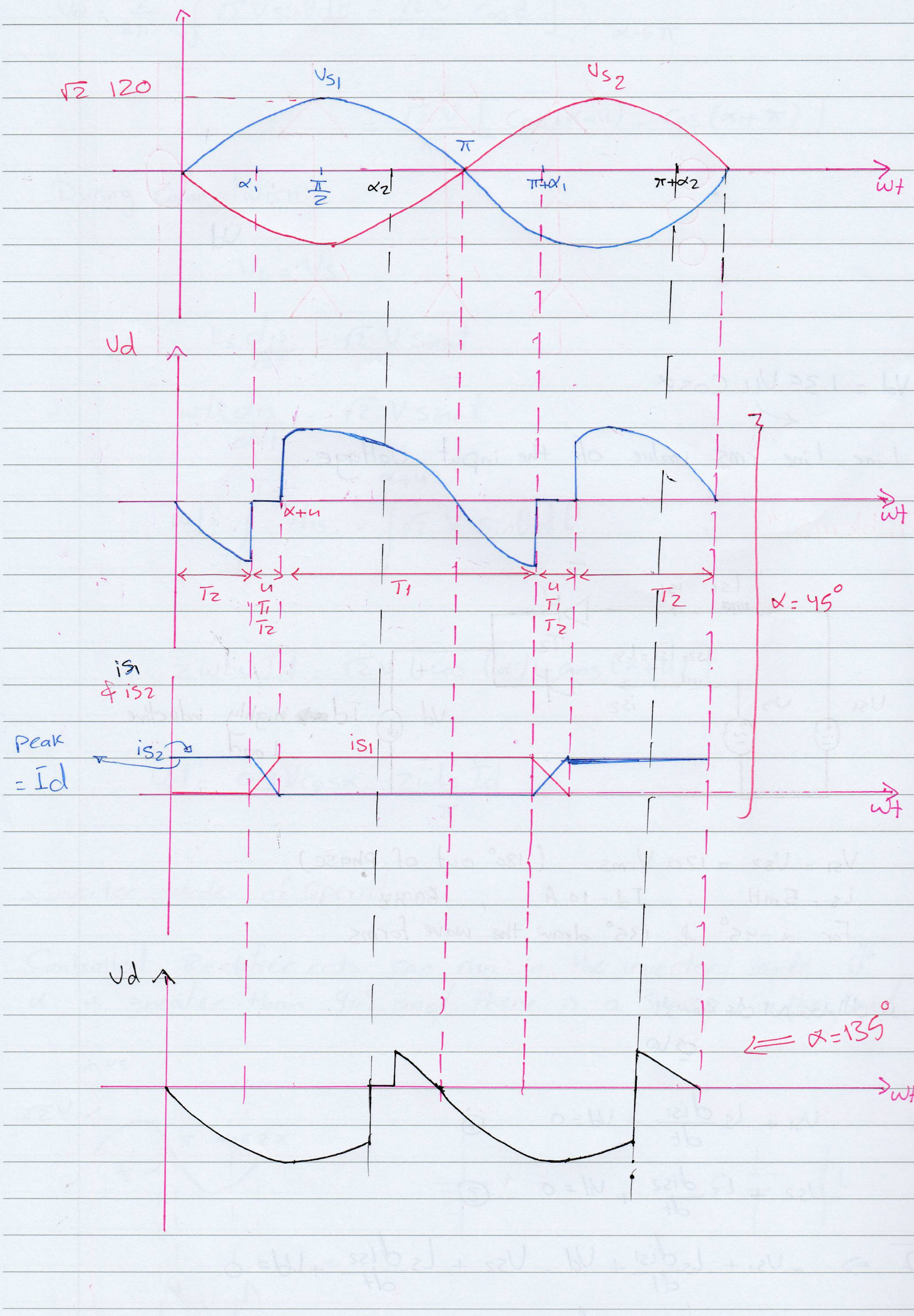
$$-V_{s2} + L_s \frac{di_{s2}}{dt} + V_d = 0 \quad \text{-- } (2)$$

$$\boxed{1+2} \Rightarrow -V_{s1} + L_s\frac{di_{s1}}{dt} + V_d - V_{s2} + L_s\frac{di_{s2}}{dt} + V_d = 0$$

$$V_{s1} = -V_{s2}, \quad \frac{di_{s1}}{dt} = -\frac{di_{s2}}{dt} \Rightarrow 2V_d = 0 \Rightarrow V_d = 0$$

during Commutation only

during Commutation.


√2 120
Vs1
Vs2
α1
π/2
α2
π
π+α1
π+α2
ωt
Vd
α+u
T2
u
T1
T1
T2
T2
α = 45°
is1
& is2
Peak
= Id
is2
is1
Vd
α = 135°

During commutation:-

$$V_{L1} = V_{S1}$$

$$\omega L_s \frac{di_{s1}}{dt} = \sqrt{2}\, V \sin\omega t$$

$$\omega L_s \frac{di_{s1}}{d\omega t} = \sqrt{2}\, V \sin\omega t$$

$$\omega L_s \int_0^{I_d} di_{s1} = \int_{\alpha}^{\alpha+u} \sqrt{2}\, V \sin\omega t \, d\omega t$$

$$\omega L_s I_d = \sqrt{2}\, V \left[\cos\alpha - \cos(\alpha+u)\right]$$

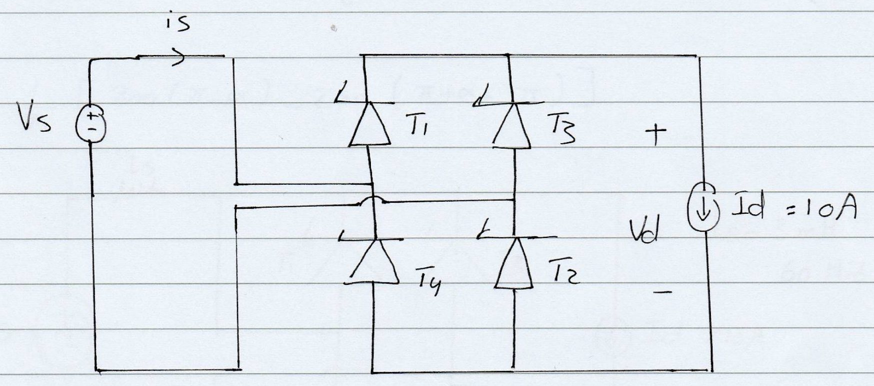
$$\omega L_s I_d = \sqrt{2}\, V \cos\alpha - \sqrt{2}\, V \cos(\alpha+u)$$

$$\cos(\alpha+u) = \frac{\sqrt{2}\, V \cos\alpha - \omega L_s I_d}{\sqrt{2}\, V} \Rightarrow$$ u بطلع

$$V_d = \frac{2}{2\pi} \int_{\alpha+u}^{\alpha+\pi} \sqrt{2}\, V \sin\omega t \, d\omega t = \frac{\sqrt{2}\, V}{\pi} \cos\omega t \Big]_{\alpha+\pi}^{\alpha+u}$$

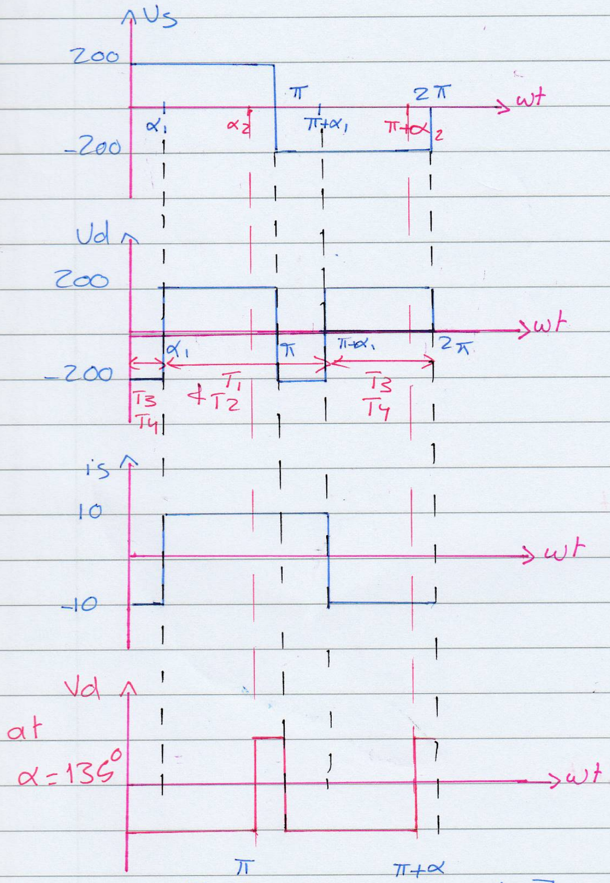
$$V_d = \frac{\sqrt{2}\, V}{\pi} \left[\cos(\alpha+u) - \cos(\alpha+\pi)\right]$$

6-3)



Vs is a square wave with amplitude of 200 V, 60 HZ

Draw wave-forms at $\alpha = 45^\circ$ & 135°

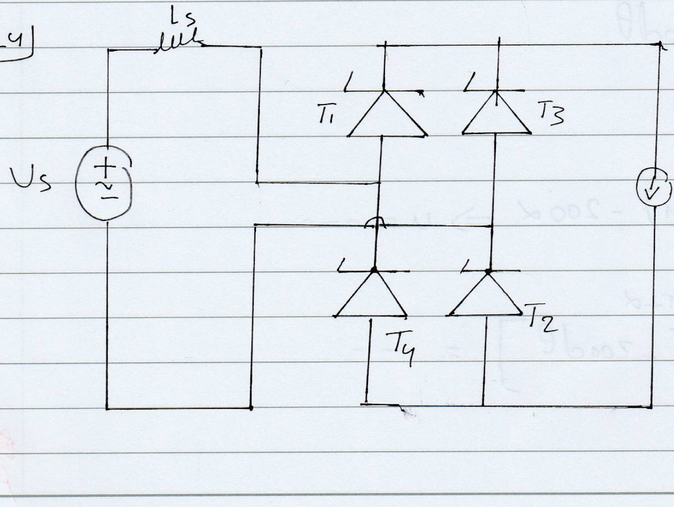


$$V_d = \frac{2}{2\pi}\left[\int_{\alpha}^{\pi} 200\, d\theta + \int_{\pi}^{\pi+\alpha} -200\, d\theta\right]$$

$$P_d = V_d I_d \Rightarrow P_d = \frac{1}{2\pi}\int_{0}^{2\pi} i_d(\theta)\, v_d(\theta)\, d\theta = \frac{10}{2\pi} \times 2 \times [\quad]$$

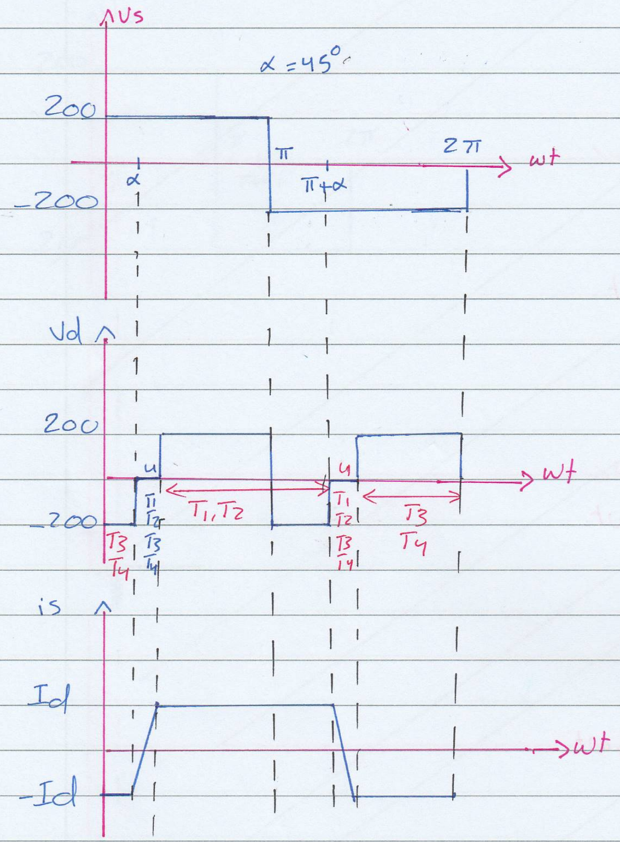
$$V_d = \frac{1}{\pi}\left[200(\pi-\alpha) - 200(\pi+\alpha-\pi)\right]$$

6-4)



$L_s = 3\,mH$

60 HZ



During commutation:-

$$V_L = V_s$$

$$wL_s \frac{di_s}{dwt} = 200$$

$$wL_s \int_{-I_d}^{I_d} di_s = \int_{\alpha}^{\alpha+u} 200 d\theta$$

$$2wL_s I_d = 200(\alpha+u) - 200\alpha \Rightarrow u = ---$$

$$V_d = \frac{2}{2\pi}\left[\int_{\alpha+u}^{\pi} 200 d\theta + \int_{\pi}^{\pi+\alpha} -200 d\theta\right] = ---$$

Chapter 7: Dc_Dc switch mode converters

18-6-2017

_ Applications:_

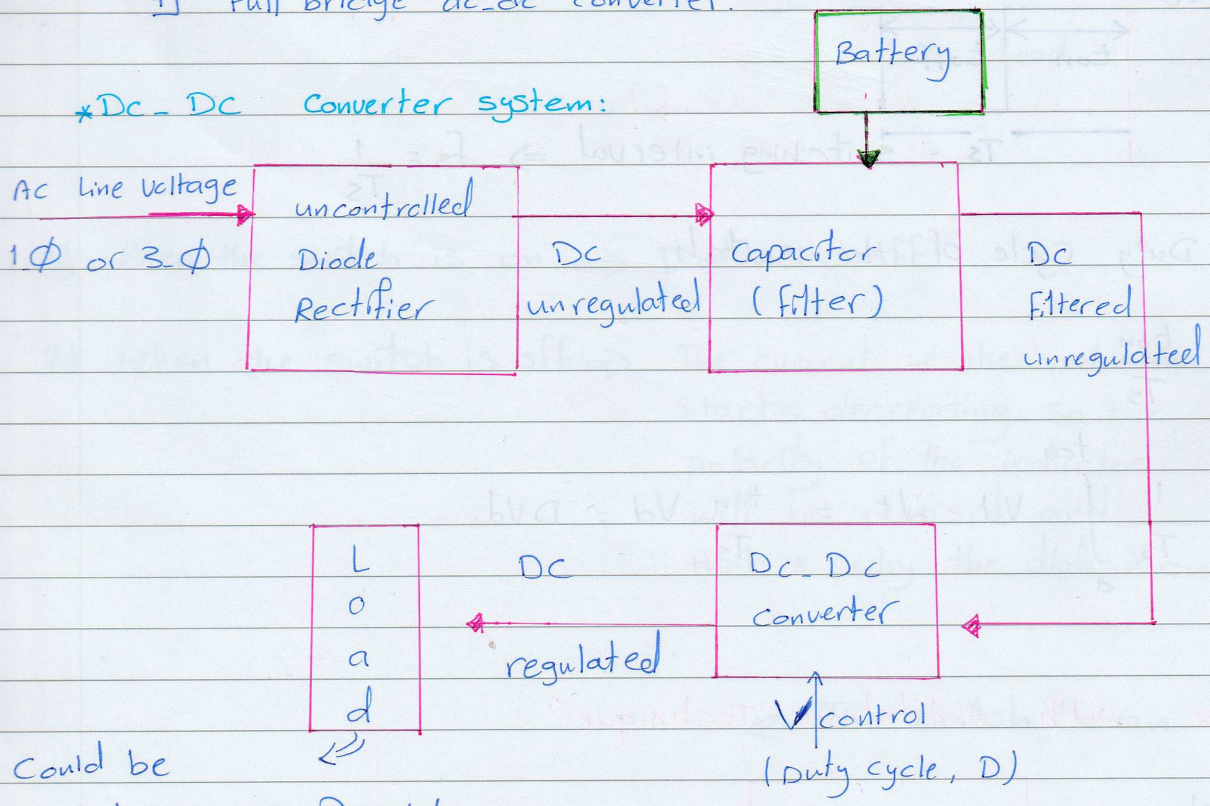
1] Dc motor drive applications.
2] Regulated power supplies.

- They are used to convert the unregulated dc input into a controlled dc output.

Types:

1] Step-down (buck) converter
2] Step_up (boost) converter.
3] Step up_stepdown (Buck_Boost) converter.
4] Full bridge dc_dc converter.

*Dc_Dc Converter system:

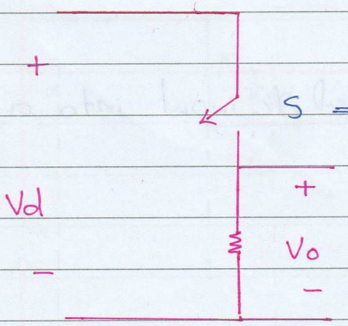


Could be resistance or Dc Motor.

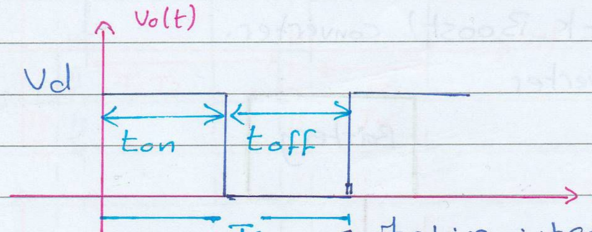
_ In this chapter:

1] The converters are analyzed in steady_state.
2] The switches are ideal (No power loss)
3] The losses in the inductive and capacitive part are neglected.

"Control of DC_DC converters"



S ⇒ could be (GTO, BJT, MOSFET)



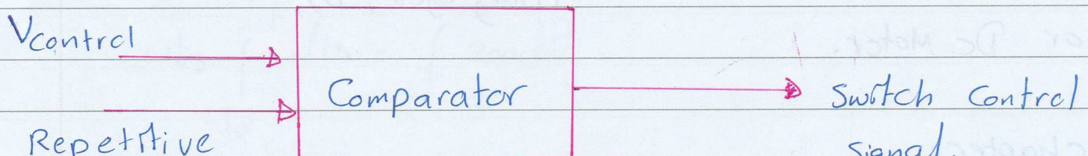
Ts = switching interval ⇒ $f_s = \frac{1}{T_s}$

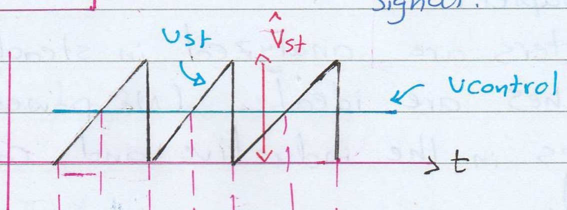
D = Duty cycle of the switch

$$D = \frac{t_{on}}{T_s}$$

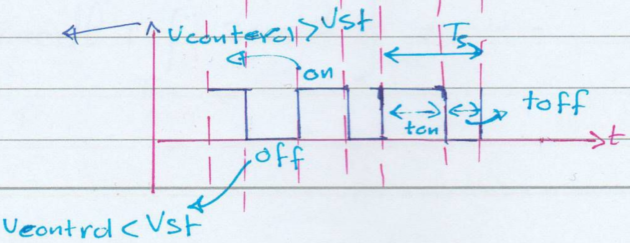
$$V_o = \frac{1}{T_s}\int_0^{t_{on}} V_d \, dt = \frac{t_{on}}{T_s} V_d = D V_d.$$

"Pulse width Modulation Technique"





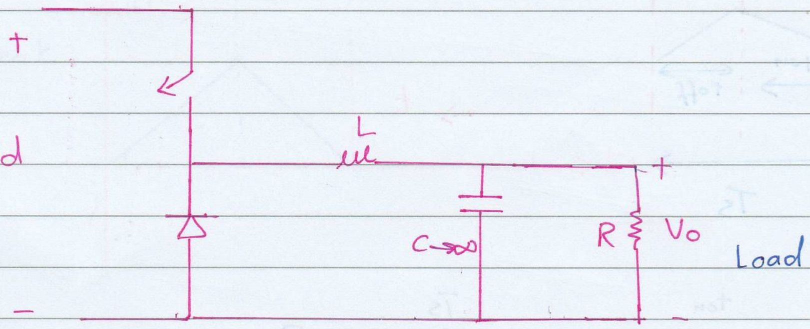
Switch Control signal.



- Dc Dc converters run in:

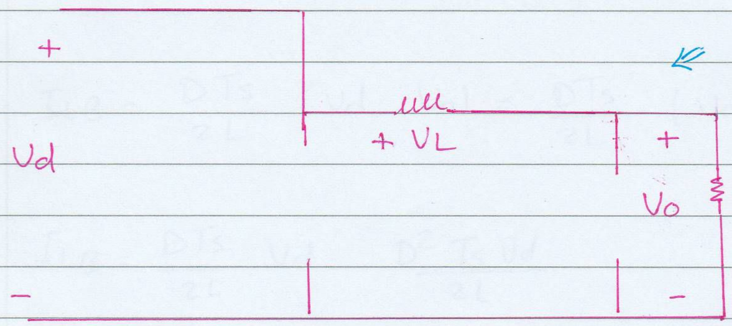
1) Contineous current conduction mode.
2) Discontineous current conduction mode.

" Step down (Buck) converter."



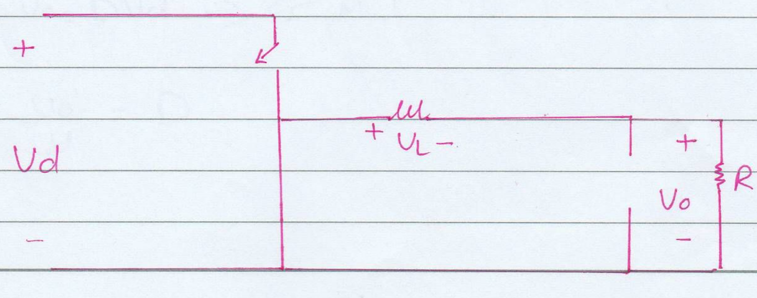
1] when the switch is on ⟹ Diode is off.

2] when the switch is off ⟹ The current in the inductor starts decreasing so the polarity of the inductor will be reversed and that is why the diode is on.



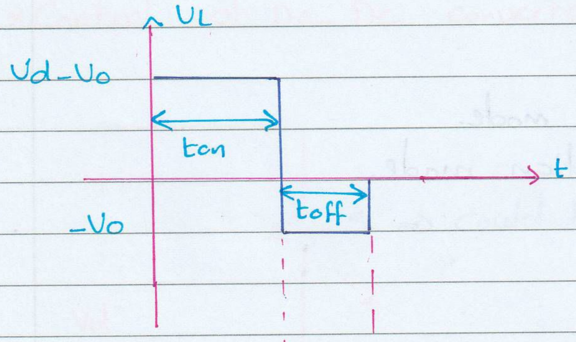
The switch is on.

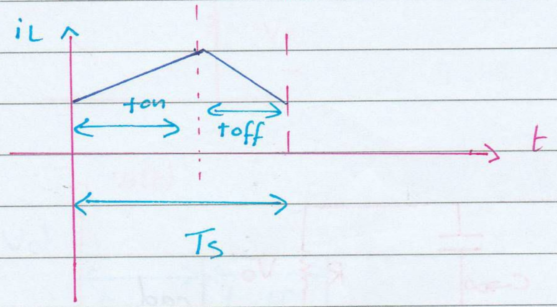
⟹ $V_L = V_d - V_o$



The switch is off

⟹ $V_L = -V_o$





$$V_L = 0 = \frac{1}{T_s}\left[\int_0^{t_{on}} (V_d - V_o)\,dt + \int_{t_{on}}^{T_s} -V_o\,dt\right]$$

$$V_L = (V_d - V_o)\,t_{on} - V_o\,(T_s - t_{on}) = 0$$

$$V_d t_{on} - V_o t_{on} - V_o T_s + V_o t_{on} = 0$$

$$V_d t_{on} = V_o T_s$$

$$\frac{V_o}{V_d} = \frac{t_{on}}{T_s} = D$$

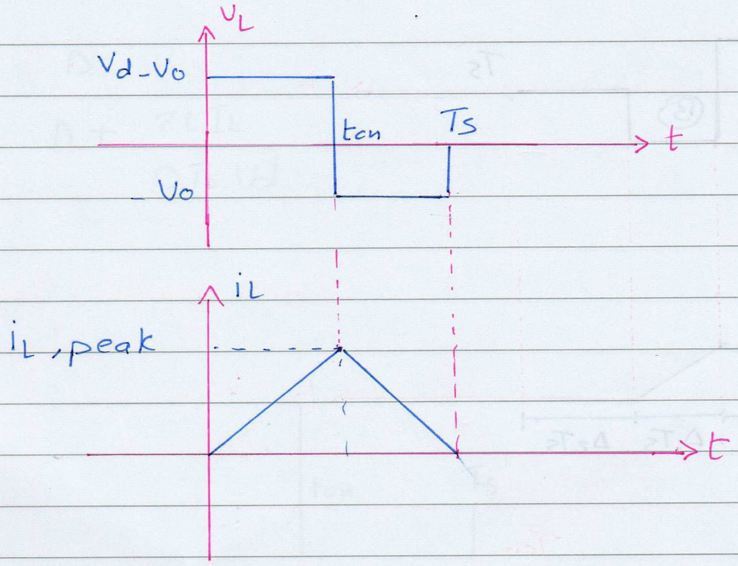
$$V_o = \frac{t_{on}}{T_s} V_d = D V_d$$

$$P_o = P_d$$

$$V_o I_o = V_d I_d$$

$$I_o = \frac{1}{D} I_d$$

1) Cont. mode:- we have current at any instant.



$$I_{LB} = \frac{1}{T_s}\left[\frac{1}{2} t_{on}\, i_{L,peak} + \frac{1}{2} t_{off}\, i_{L,peak}\right]$$

$$I_{LB} = \frac{1}{2} i_{L,peak}$$

$$i_L(t) = \frac{1}{L}(V_d - V_o)\, t$$

$$i_{L,peak} = \frac{1}{L}(V_d - V_o)\, t_{on}$$

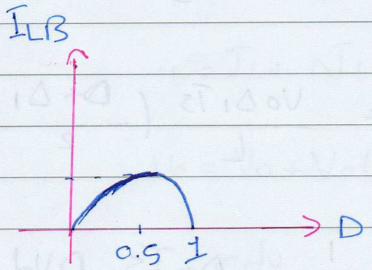
$$\therefore \quad I_{LB} = \frac{t_{on}}{2L}(V_d - V_o) \quad , \quad D = \frac{t_{on}}{T_s}$$

$$I_{LB} = \frac{DT_s}{2L}(V_d - V_o) = \frac{DT_s}{2L}(V_d - DV_d)$$

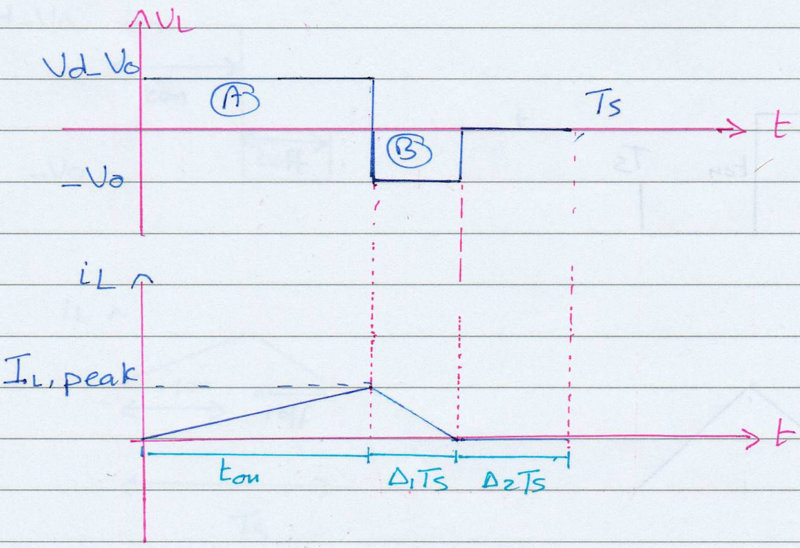
$$I_{LB} = \frac{DT_s}{2L} V_d - \frac{D^2 T_s V_d}{2L}$$

$\Rightarrow$ $V_o = DV_d \Rightarrow$ C.C.M

$$\frac{V_o}{V_d} = D$$



* Discontineous mode :-



$$A = B \Rightarrow (V_d - V_o)\overset{T_{on}}{DT_s} = V_o \Delta_1 T_s$$

$$V_d(DT_s) = V_o \Delta_1 T_s + V_o D T_s$$

$$\frac{V_o}{V_d} = \frac{D}{D+\Delta_1} \Rightarrow$$ not the same ratio.

$$\Rightarrow I_L = \frac{1}{T_s}\left(\frac{1}{2} i_{L,peak}\, \overset{t_{on}}{DT_s} + \frac{1}{2} i_{L,peak}\, \Delta_1 T_s\right)$$

$$I_L = i_{L,peak}\left(\frac{D+\Delta_1}{2}\right)$$

$$i_{L,peak} = \frac{(V_d - V_o)}{L} DT_s$$

$$i_{L,peak} = \frac{V_o}{L}\Delta_1 T_s$$

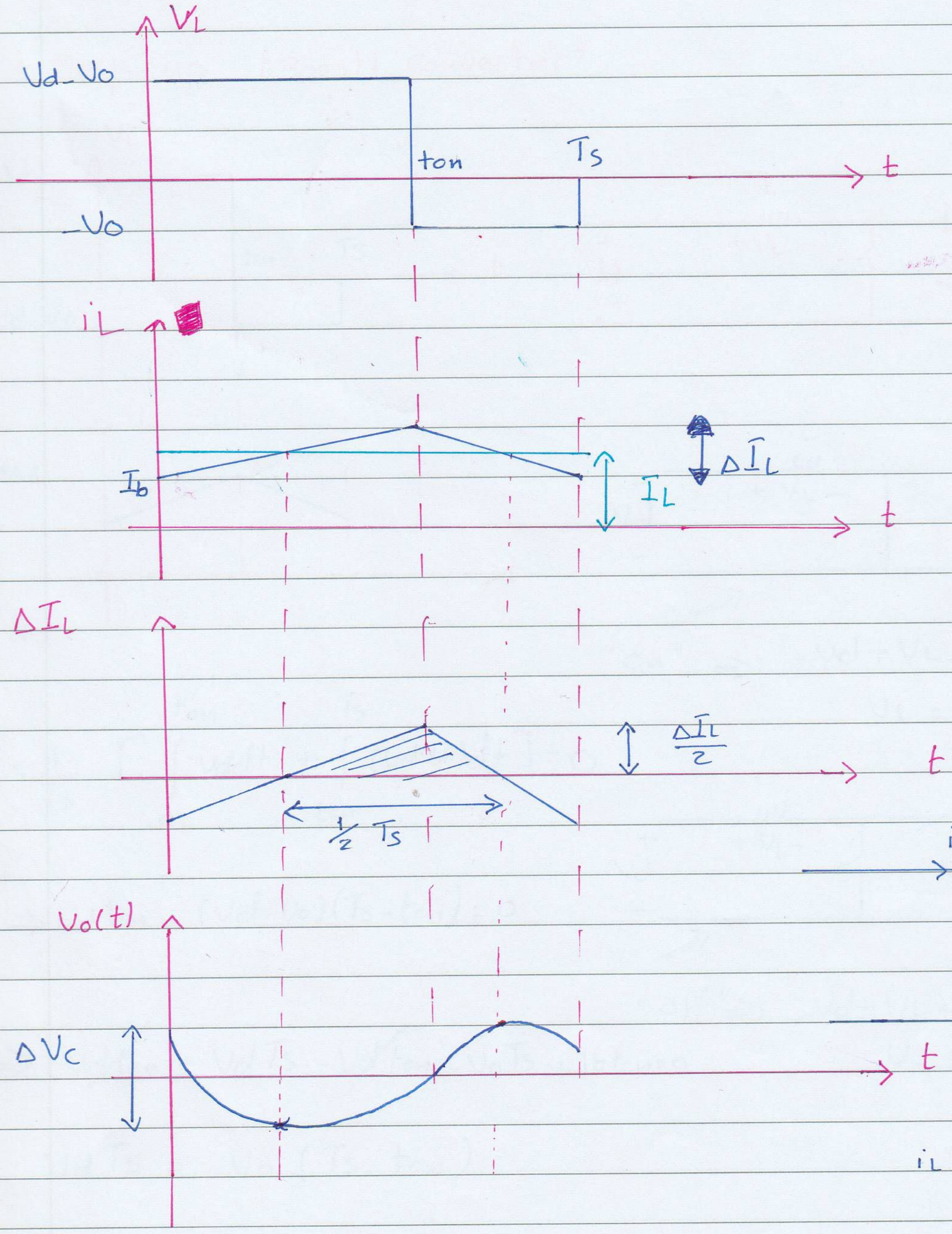
$$I_L = \frac{V_o \Delta_1 T_s}{L}\left(\frac{D+\Delta_1}{2}\right) = \left(\frac{D+\Delta_1}{2}\right)\frac{1}{L}\Delta_1 T_s\left(\frac{V_d D}{D+\Delta_1}\right)$$

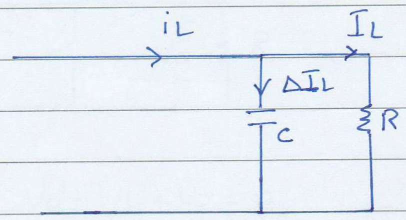
$$I_L = \frac{1}{2L} \cdot \Delta_1 T_s D V_d$$

$$\Delta_1 = \frac{2L I_L}{D T_s V_d}$$

$$\frac{V_o}{V_d} = \frac{D}{D + \frac{2L I_L}{D T_s V_d}}$$

"Output voltage ripple"





$$i_L = I_L + \Delta I_L$$

$$v_o = V_o + V_o(t)$$

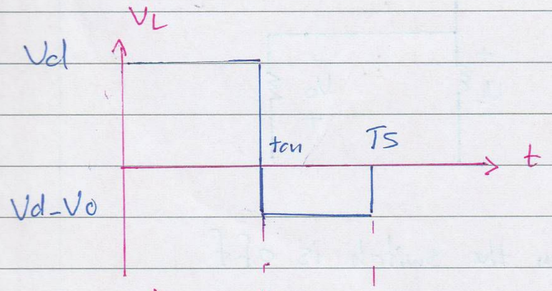
$$i = \frac{C\,dv}{dt}$$

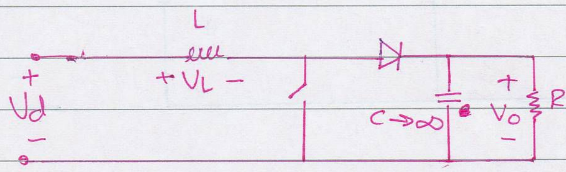
$$\Delta V_o = \frac{\Delta Q}{C} = \frac{1}{C} \times \frac{1}{2}\left(\frac{1}{2} T_s \frac{\Delta I_L}{2}\right)$$

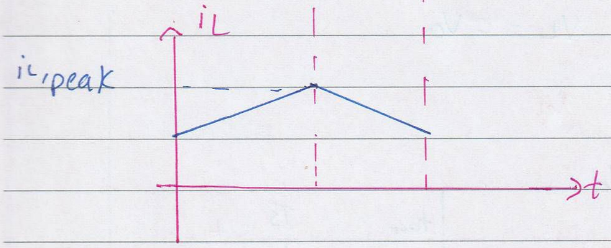
$$\Delta I_L = \frac{V_o}{L}(1-D)T_s$$

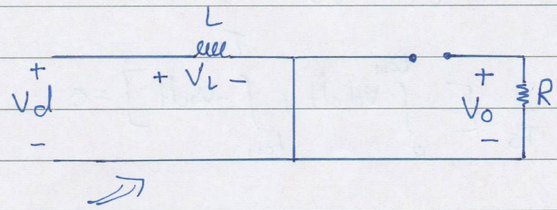
$$\frac{\Delta V_o}{V_o} = \frac{1}{8}\, T_s^2 \frac{(1-D)}{LC} = \frac{1}{8}\frac{(1-D)}{LC f_s^2}$$

"Step_up (Boost) Converter"





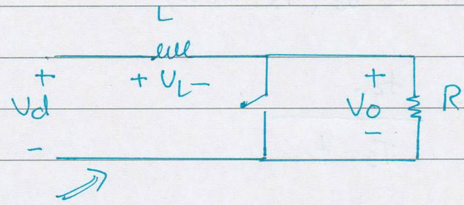




"On" $\Rightarrow$ $-V_d + V_L = 0$

$V_L = V_d$

$$V_L = \frac{1}{T_s}\left[\int_0^{t_{on}} V_d\,dt + \int_{t_{on}}^{T_s} (V_d - V_o)\,dt\right] = 0$$



$\Rightarrow V_d t_{on} + (V_d - V_o)(T_s - t_{on}) = 0$

"off" $\Rightarrow$ $-V_d + V_L + V_o = 0$

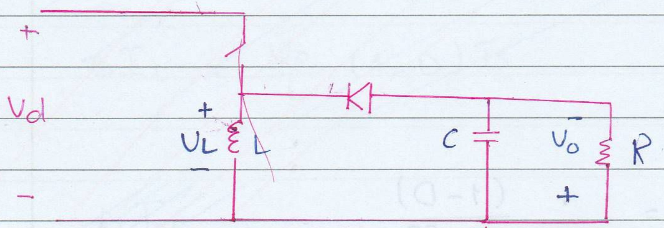
$V_L = V_d - V_o$

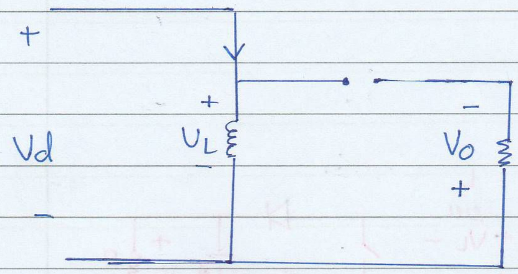
$\Rightarrow \cancel{V_d t_{on}} + V_d T_s - \cancel{V_d t_{on}} - V_o T_s + V_o t_{on} = 0$

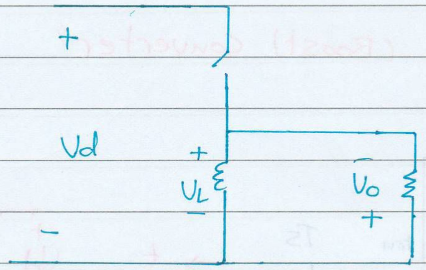
$V_d T_s = V_o (T_s - t_{on})$

$$\frac{V_o}{V_d} = \frac{T_s}{T_s - t_{on}} = \frac{T_s}{T_s - DT_s} = \frac{1}{1-D}$$ $\Rightarrow$ This ratio is always greater than 1.

"Buck_Boost converter"







when the switch is on.

$V_L = V_d$

when the switch is off

$V_L = -V_o$

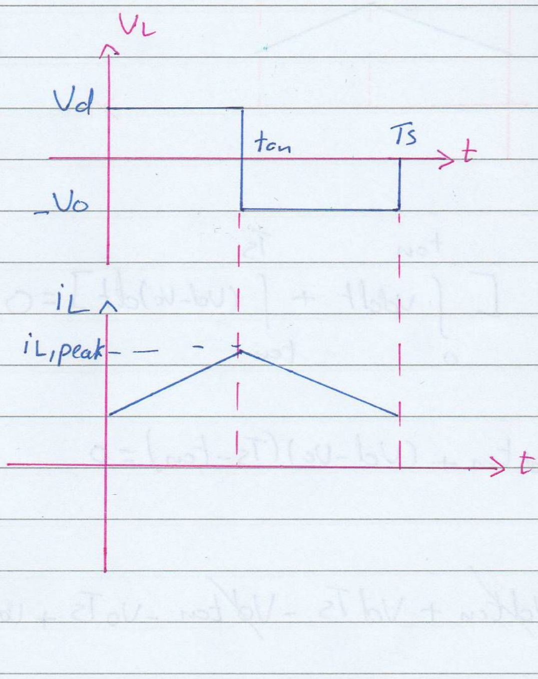
$$V_L = \frac{1}{T_s}\left[\int_0^{t_{on}} V_d\,dt + \int_{t_{on}}^{T_s} -V_o\,dt\right] = 0$$

$\Rightarrow V_d t_{on} - V_o(T_s - t_{on}) = 0$

$V_d t_{on} = V_o(T_s - t_{on})$

$$\frac{V_o}{V_d} = \frac{t_{on}}{T_s - t_{on}}$$

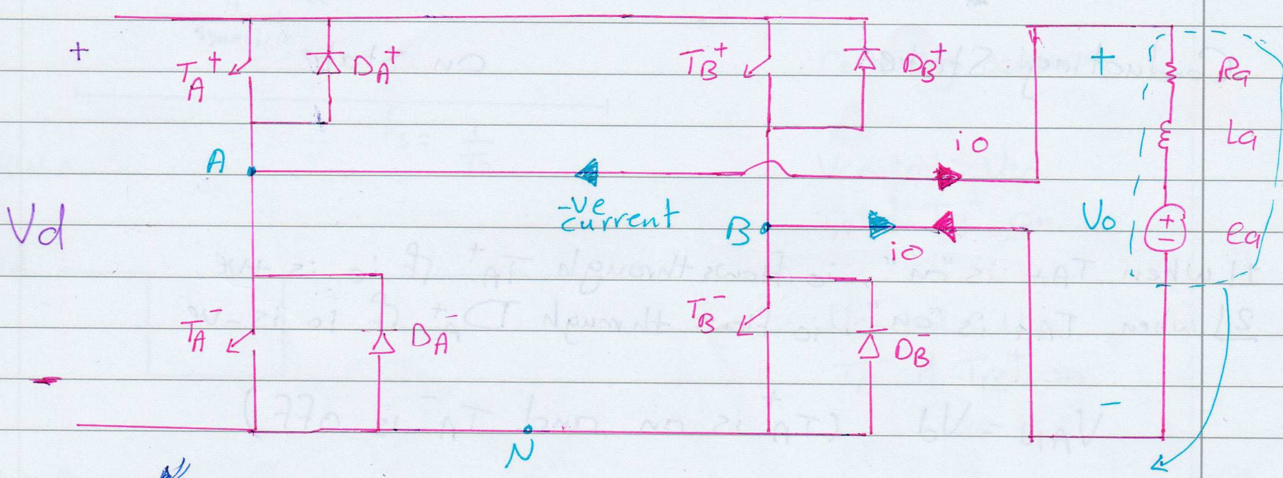
$$\frac{V_o}{V_d} = \frac{DT_s}{T_s - DT_s} = \frac{D}{1-D}$$



"Full - Bridge dc-dc converter"

1) dc motor drive systems.
2) regulated power supplies.
3) dc-ac conversion (inverter)

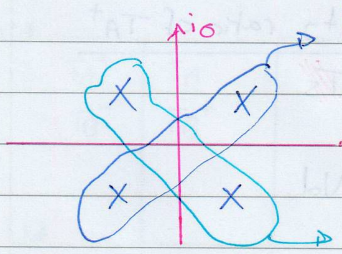
* -Ve direction for the current passes through the diodes



Dc Motor (highly inductive Load)

T_A^+ & T_A^- or T_B^+ & T_B^- can't be open at the same time because of Vd.

$V_o = V_{AN} - V_{BN}$



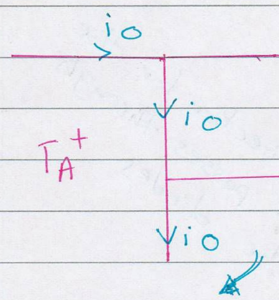
from the source to the Load

⟸ 4-quardrant operation

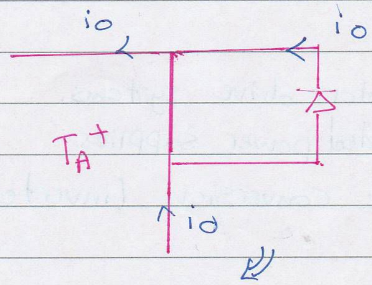
From the Load to the source

⇒ on-state of the switch:- The switch is on and the current flows through the anti parallel diode

⇒ Conducting-state of the switch:- The switch is on and the current flows throug it (+ve direction of the current).



Conducting _State



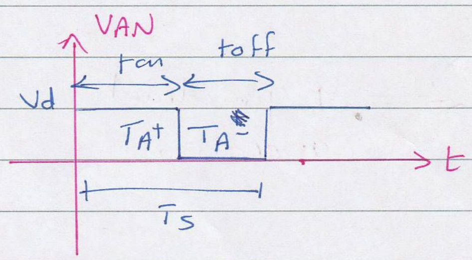
On _State

1] when T_{A+} is "on", io flows through T_A^+ if io is +ve
2] when T_{A+} is "on", io flows through D_A^+ if io is -ve

$$V_{AN} = V_d \quad (T_A^+ \text{ is on and } T_A^- \text{ is off})$$

1] when T_{A-} is "on", io flows through T_A^- if io is -ve
2] when T_{A-} is "on", io flows through D_A^- if io is +ve

$$V_{AN} = 0$$



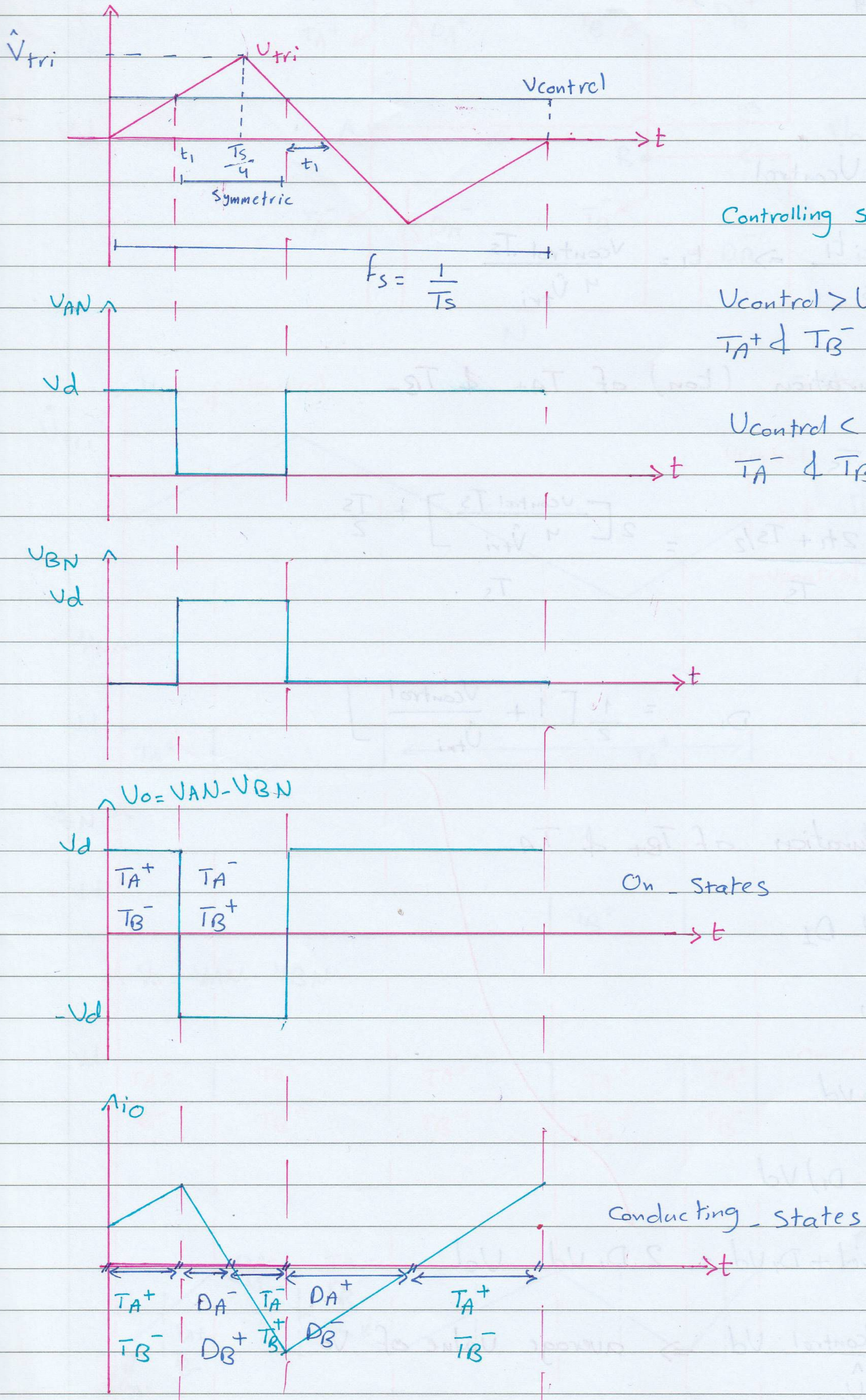
$$V_{AN} = V_d * \text{Duty ratio of } T_A^+$$

$$V_{AN} = \frac{t_{on}}{T_s} V_d$$

$$V_{BN} = V_d * \text{Duty ratio of } T_B^+ \Rightarrow \frac{t_{on}}{T_s}$$

and these two are independent of the direction of io

"PWM with Bipolar voltage switching"



Controlling scheme:-

$V_{control} > V_{tri}$

T_A^+ & T_B^- on

$V_{control} < V_{tri}$

T_A^- & T_B^+ on

4 quardrants.

$$V_{tri} = \hat{V}_{tri} \frac{t}{T_s/4} = \frac{4 \hat{V}_{tri}\, t}{T_s}, \quad 0 < t < \frac{T_s}{4}$$

at $t = t_1$

$$V_{tri} = V_{control}$$

$$V_{control} = \frac{4 \hat{V}_{tri}\, t_1}{T_s} \Rightarrow t_1 = \frac{V_{control} . T_s}{4 \hat{V}_{tri}}$$

⇒ The on duration (t_{on}) of T_{A+} & T_{B-}

$$t_{on} = 2 t_1 + \frac{1}{2} T_s$$

$$D_1 = \frac{t_{on}}{T_s} = \frac{2t_1 + T_s/2}{T_s} = \frac{2\left[\frac{V_{control} . T_s}{4 \hat{V}_{tri}}\right] + \frac{T_s}{2}}{T_s}$$

$$D_1 = \frac{1}{2}\left[1 + \frac{V_{control}}{\hat{V}_{tri}}\right]$$

⇒ The on duration of T_{B+} & T_{A-}

$$D_2 = 1 - D_1$$

$$V_o = V_{AN} - V_{BN}$$

$$V_o = D_1 V_d - D_2 V_d$$

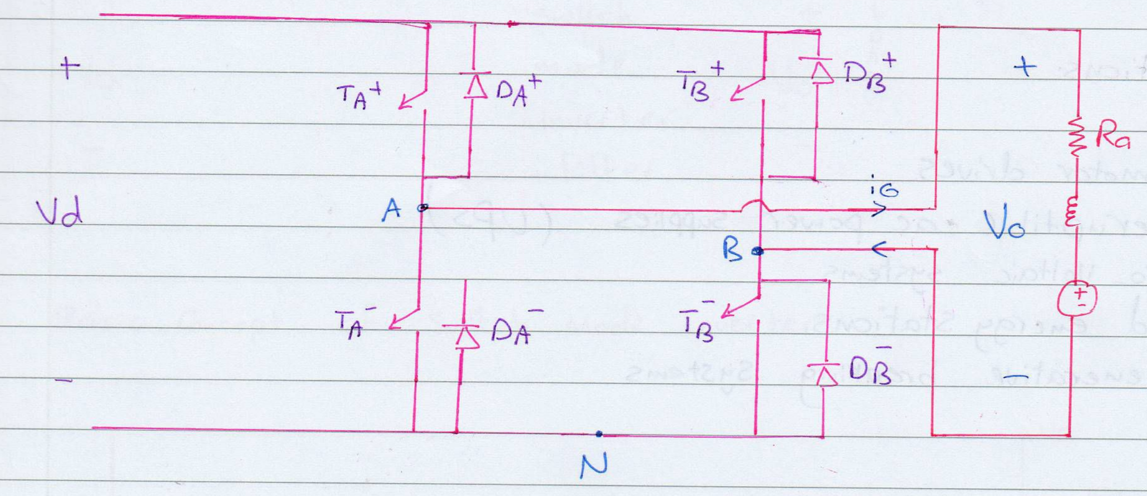
$$= D_1 V_d - (1 - D_1) V_d$$

$$= D_1 V_d - V_d + D_1 V_d = 2 D_1 V_d - V_d$$

$$V_o = K V_d = \frac{V_{control}}{\hat{V}_{tri}} V_d$$ ⇒ average value of V_o

"Chp7" 2-7-2017

"PWM with uni-polar voltage switching



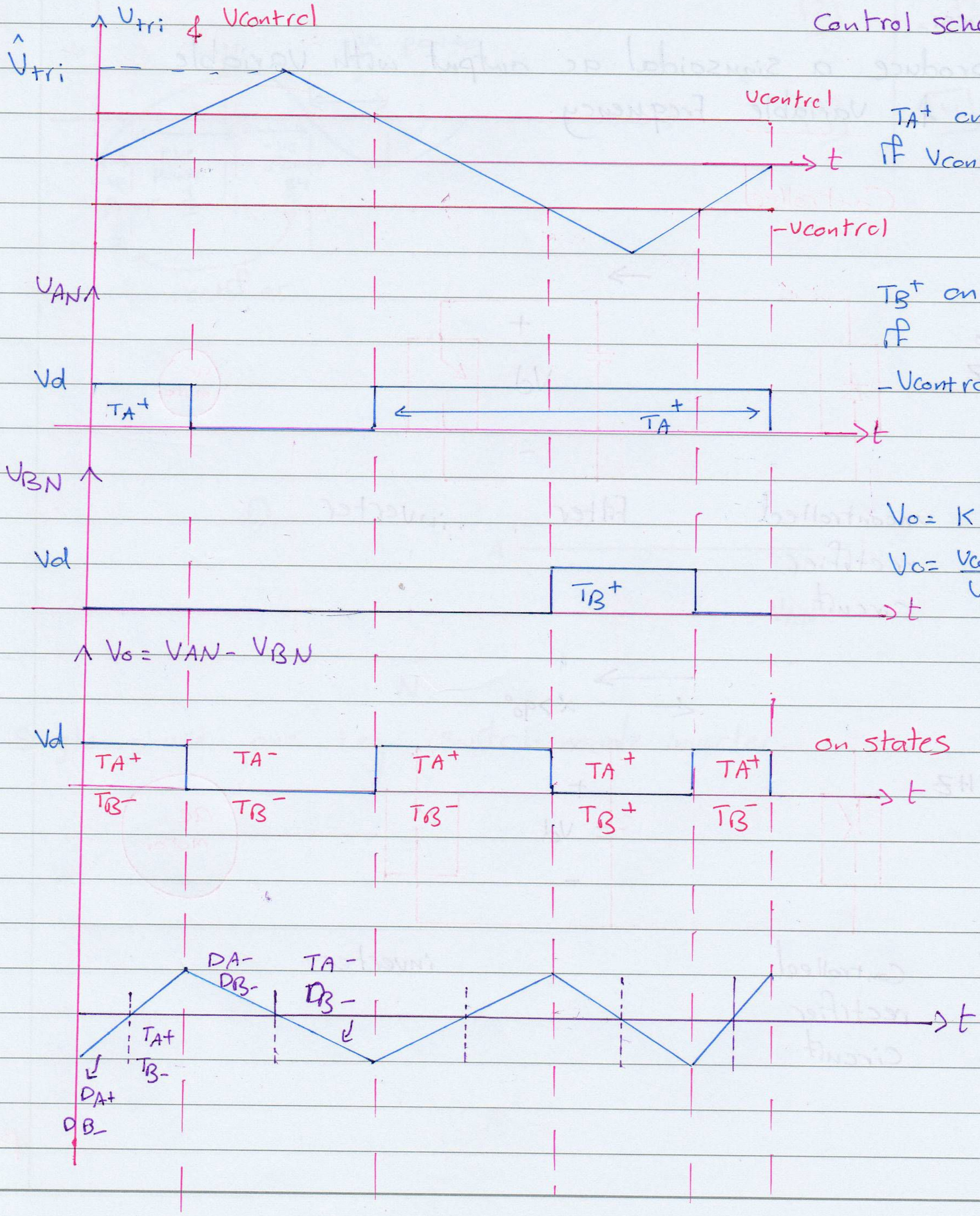
Control scheme:-

T_A^+ on if $V_{control} > U_{tri}$

T_B^+ on if $-V_{control} > U_{tri}$

$V_o = K\,Vd$

$V_o = \frac{V_{control}}{U_{tri}} \cdot Vd$



"Chp 8" Switch Mode dc-ac Inverters 3.7.2017

dc ⟷ sinusoidal ac.

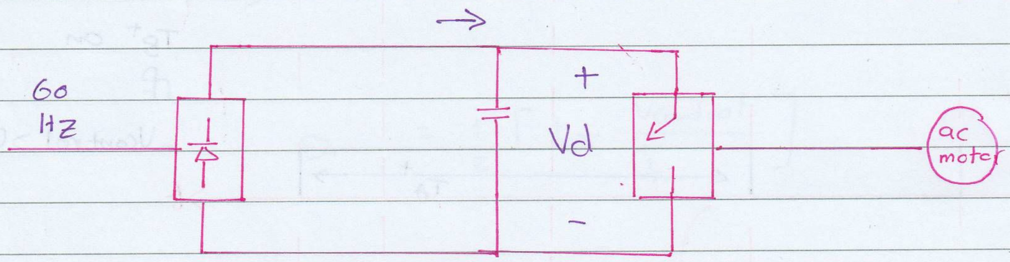
Applications:-

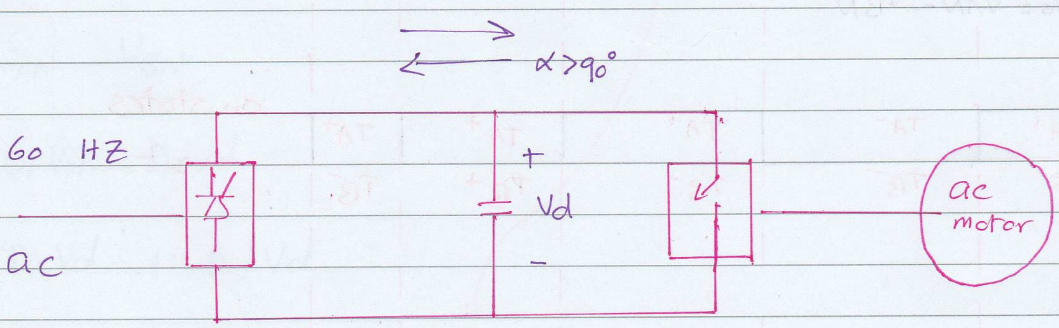
1) ac motor drives
2) uninteruptible ac power supplies (UPS)
3) Photo-Voltaic systems
4) Wind energy stations
5) regenerative breaking systems.

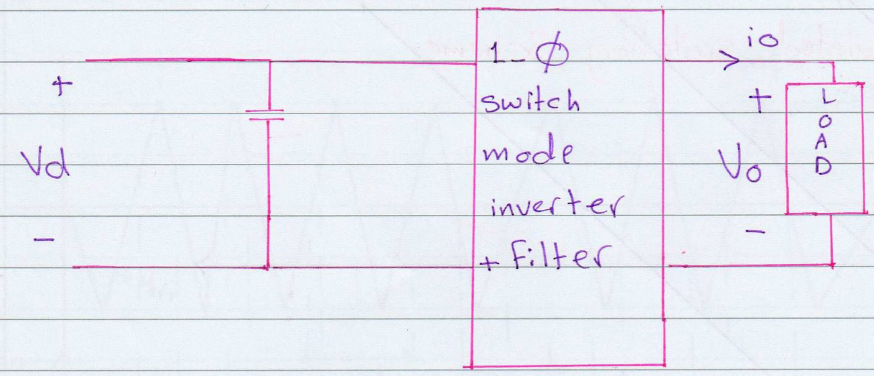
Objectives:-

To produce a sinusoidal ac output with variable magnitude & variable frequency

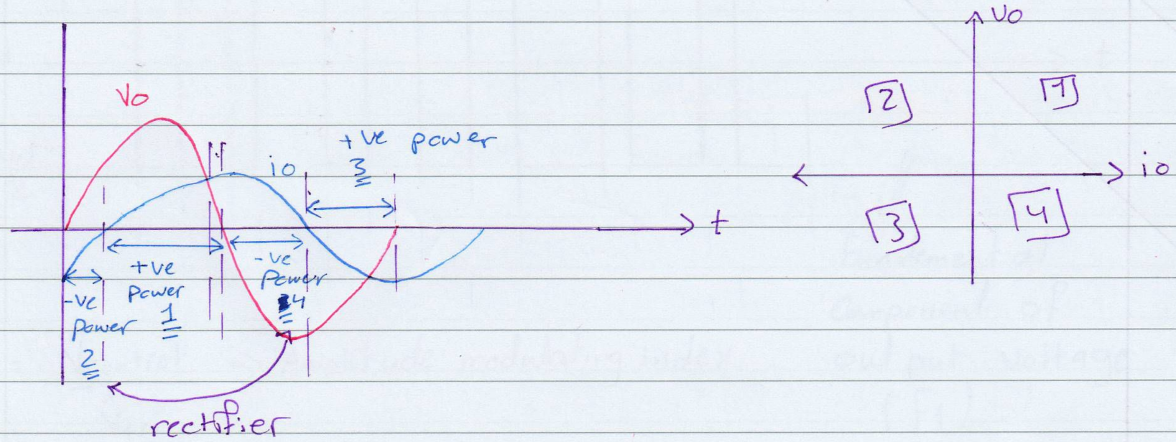
Controlled.

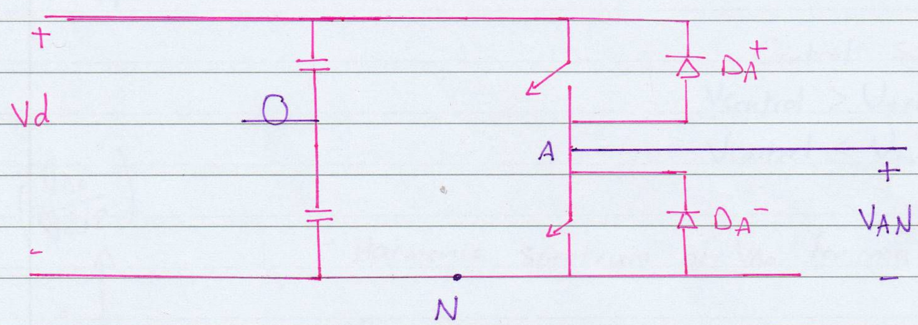






Basic Concept of Switch-Mode Inverters



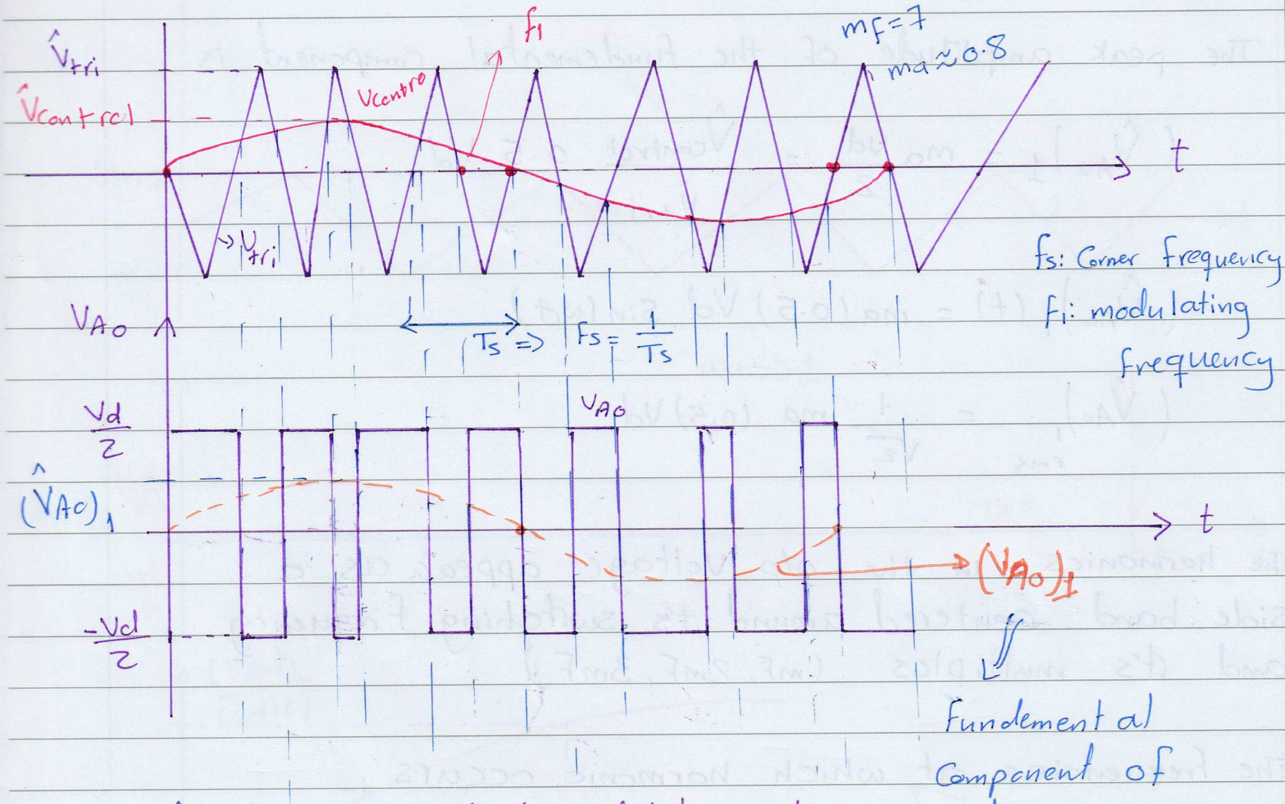


Single-phase one-Leg switch mode inverter.

"Chp8"

3 - 7 - 2017

"Pulse Width Modulated switching"



f_s: Corner frequency

f_1: modulating frequency

$m_a = \frac{\hat{V}_{control}}{\hat{V}_{tri}} \Rightarrow$ Amplitude modulating index

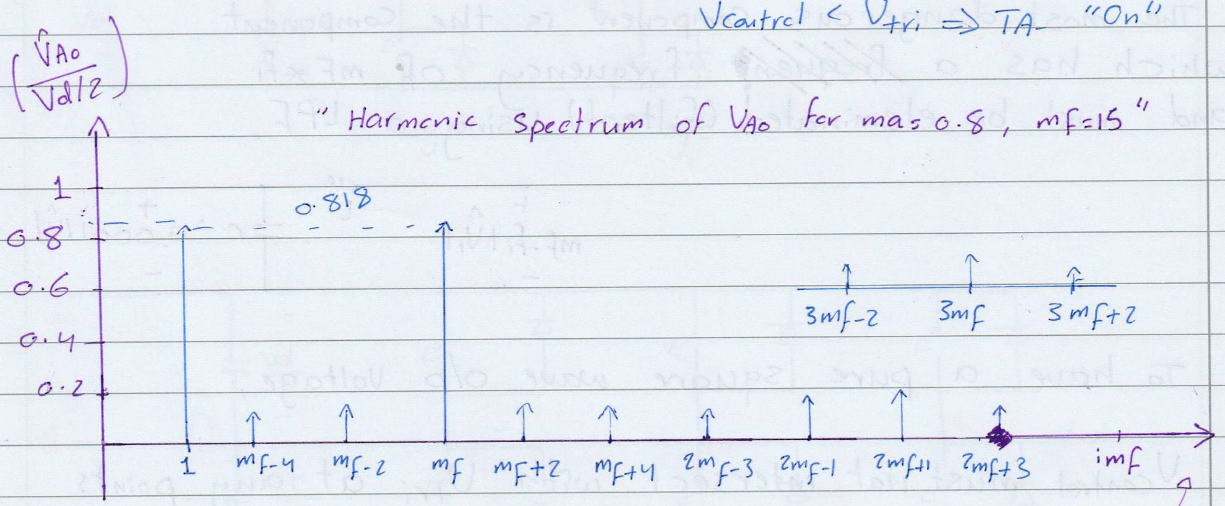
$m_f = \frac{F_s}{F_1} \Rightarrow$ Frequency modulating index

Control Scheme:

$V_{control} > V_{tri} \Rightarrow T_{A+}$ "On"

$V_{control} < V_{tri} \Rightarrow T_{A-}$ "On"

"Harmonic Spectrum of V_{Ao} for $m_a = 0.8$, $m_f = 15$"



$\hat{V}_{Ao} = 0.8 \frac{V_d}{2}$

$\Rightarrow (\hat{V}_{Ao})_{m_f} = (\hat{V}_{Ao})_{15} = 0.818 \frac{V_d}{2}$

$\hat{V}_{Ao} = m_a \frac{V_d}{2}$

$(15 \times f_1 \; HZ)$

"Notes on PWM":-

1] The peak amplitude of the fundemental component is

$$(\hat{V}_{Ao})_1 = ma \frac{Vd}{2} = \frac{\hat{V}_{control}}{\hat{V}_{tri}} 0.5\ Vd$$

$$(\hat{V}_{Ao})_1(t) = ma(0.5)\,Vd\ \sin(w_1 t)$$

$$(\hat{V}_{Ao})_{1_{rms}} = \frac{1}{\sqrt{2}}\ ma\ (0.5)\,Vd$$

2] The harmonics in the o/p voltage appear as a side band centered around it's switching frequency and it's multiples (mF, 2mF, 3mF)

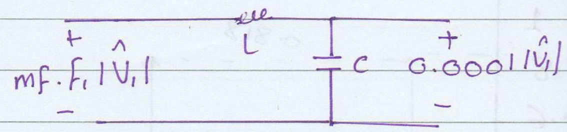
3] The frequencies at which harmonic occurs :-

$$f_h = (jm_F \pm K) f_1 = h f_1$$

if j is odd ; K is even

if j is even , K is odd

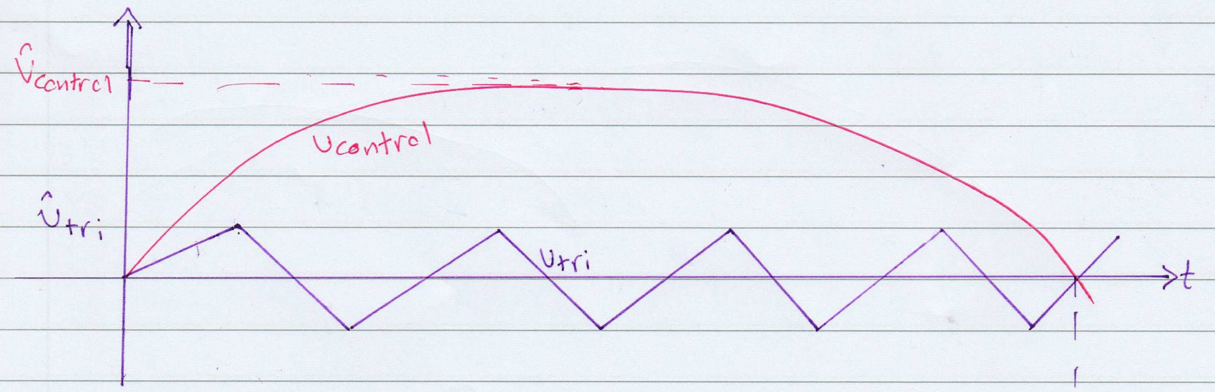
4] The most dangerous component is the component which has a ~~frequen~~ frequency of $mF * f_1$ and must be eleminated (filterd) using a LPF

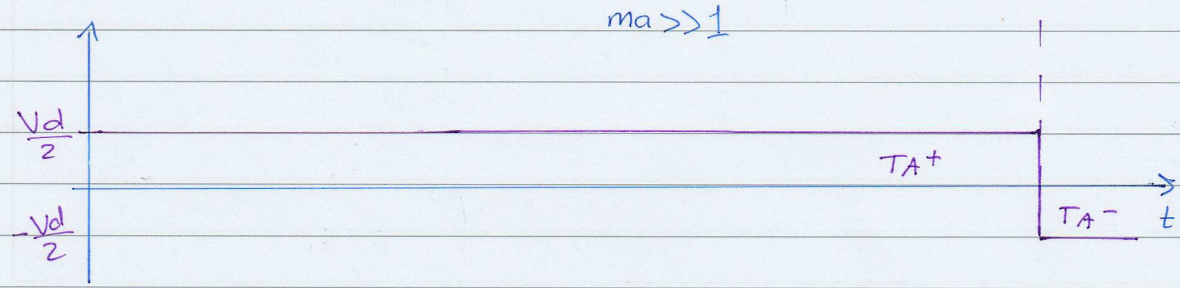


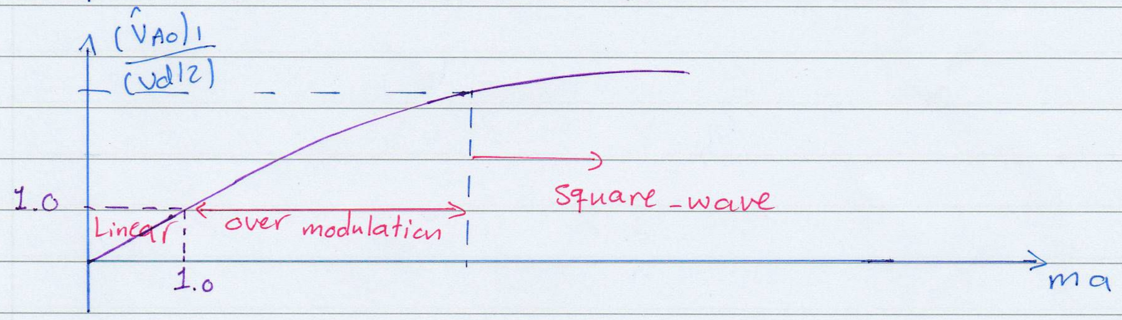
5] To have a pure square wave o/p voltage,

$V_{control}$ must not intersect with V_{tri} at any points except the zero crossing

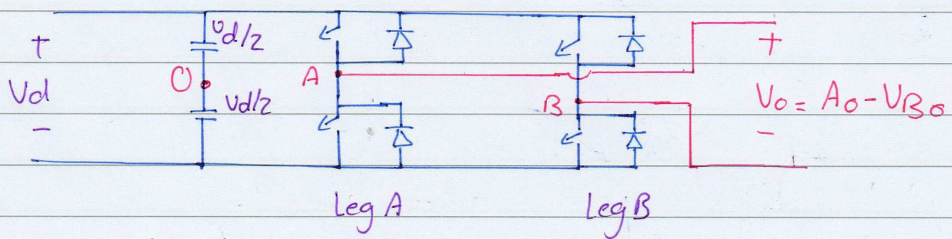
 4-7-2017







"1-φ full bridge switch mode inverter"



"3-φ inverter"