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Power Electronics

※ Harmonics:

- $f(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos n\omega_0 t + b_n \sin n\omega_0 t) \longrightarrow$ $\boxed{a_0 = \frac{1}{T}\int_T f(t)\,dt}$, $\boxed{a_n = \frac{2}{T}\int_T f(t)\cos(n\omega_0 t)\,dt}$, $\boxed{b_n = \frac{2}{T}\int_T f(t)\sin(n\omega_0 t)\,dt}$

- $f(t) = a_0 + \sum_{n=1}^{\infty} C_n \cos(n\omega_0 t + \theta_n)$ $\longrightarrow$ $\boxed{C_n = \sqrt{a_n^2 + b_n^2}}$, $\boxed{\theta_n = \tan^{-1}\left(\frac{-b_n}{a_n}\right)}$

- $f(t) = a_0 + \sum_{n=1}^{\infty} C_n \sin(n\omega_0 t + \theta_n) \longrightarrow \boxed{\theta_n = \tan^{-1}\left(\frac{a_n}{b_n}\right)}$

- RMS: $\boxed{F_{rms} = \sqrt{a_0^2 + \sum_{n=1}^{\infty}\left(\frac{C_n}{\sqrt{2}}\right)^2}}$

* For Non linear $V(t)$ & $I(t)$: $\boxed{P_{avg} = V_0 I_0 + \sum_{n=1}^{\infty} V_{rms,n} I_{rms,n} \cos(\theta_n - \phi_n)}$

* For Linear $V_s(t)$ & Non linear $I(t)$:

$$\boxed{P_{avg} = V_{s,rms} I_{1,rms} \cos(\theta_s - \phi_1)}$$

$$\boxed{PF = \frac{I_{1,rms}}{I_{rms}} \cos(\theta_s - \phi_1)}$$

$$\boxed{I_{rms} = \sqrt{I_0^2 + \sum_{n=1}^{\infty}\left(\frac{I_n}{\sqrt{2}}\right)^2}}$$

$$\boxed{DF = \frac{I_{1,rms}}{I_{rms}}}$$

- THD: $\boxed{THD = \sqrt{\frac{I_{rms}^2 - I_{1,rms}^2}{I_{1,rms}^2}}}$, $\boxed{DF = \sqrt{\frac{1}{1 + (THD)^2}}}$

* Complex Power:

$$\boxed{S = \sqrt{P^2 + Q^2 + D^2}} \longrightarrow \boxed{D = V_{1,rms}\sqrt{\sum_{n\neq 1}^{\infty} I_{n,rms}^2}}$$

@ fundemental.

* Switch: $\underline{T_{on} = DT} \Rightarrow \boxed{D = \frac{T_{on}}{T}}$, $\boxed{T = T_{on} + T_{off}}$

- Assumptions:

@ steady state:

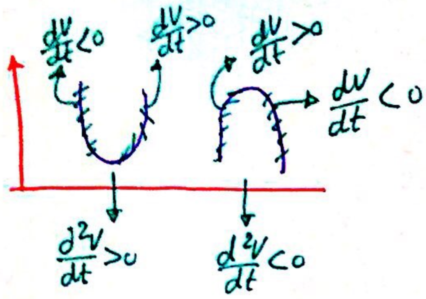
$I_{C_{avg}} = 0$ & $V_{L_{avg}} = 0$

@ C.C.M:

$I_{L_{min}} > 0$

• RMS for Sawtooth Signal:

$$RMS = \sqrt{DC^2 + \left(\frac{\frac{\Delta i_L}{2}}{\sqrt{3}}\right)^2}$$



※ Buck :

• cct: V_{in} S D L C R

• C.C.M :

$$(\Delta i_L)_{close} = \frac{DT}{L}(V_{in}-V_o)$$

$$(\Delta i_L)_{open} = \frac{-V_o T}{L}(1-D)$$

$$\boxed{V_o = D V_{in}}$$

$$I_{L_{\substack{max\\min}}} = \frac{V_o}{R} \pm \frac{V_o T(1-D)}{2L}$$

$\Rightarrow$ $I_{L_{avg}} = I_{o_{avg}}$, $I_{S_{avg}} = D\, I_{L_{avg}}$, $I_{D_{avg}} = (1-D)\, I_{L_{avg}}$

$$L_{min} = \frac{RT(1-D)}{2} \quad , \quad C = \frac{(1-D)}{8Lf^2 * Ripple} \quad , \quad I_{C_{\substack{max\\min}}} = \pm \frac{T V_o (1-D)}{2L}$$

$\boxed{L = 1.25 L_{min}}$

$\boxed{Ripple = \frac{\Delta V_o}{V_o}}$

* if there is r_c : $\Delta V_o = \Delta i_c\, r_c$, $\Delta i_c = \frac{V_o(1-D)}{Lf}$ $\Rightarrow$ $Ripple = \frac{\Delta V_o}{V_o}$

• D.C.M :

$P_{in} = P_{out}$ (ideally).

$$\boxed{\begin{aligned} I_{L_{min}} &= 0 \\ I_{L_{max}} &= \frac{DT(V_{in}-V_o)}{L} \end{aligned}}$$

* To find D_1: Take Av. for i_L.

** { @ D.C.M : $D_1 < 1-D$
@ C.CM : $D_1 > 1-D$

$$V_o = V_{in}\frac{D}{D+D_1} \quad , \quad D_1 = \frac{-D + \sqrt{D^2 + \frac{8L}{RT}}}{2}$$

※ Boost:

• cct: V_{in} L S $\vec{D}$ C R

• **C.C.M:**

$$(\Delta i_L)_{close} = \frac{V_{in} D}{Lf}$$

$$(\Delta i_L)_{open} = \frac{(1-D)}{Lf}(V_{in}-V_o)$$

$$V_o = \frac{V_{in}}{1-D}, \quad I_{L_{avg}} = \frac{V_{in}}{R(1-D)^2}$$

$$\boxed{\Delta i_c' = I_{L_{max}}.}$$

$$I_{L_{\substack{max\\min}}} = \frac{V_{in}}{R(1-D)^2} \pm \frac{V_{in} D}{2Lf}$$

$$L_{min} = \frac{RD}{2f}(1-D)^2 \rightarrow L = 1.25 L_{min}$$

$$C = \frac{DT}{R * Ripple.}$$

* if there is r_c: same as Buck.
* if there is r_L:

$P_{in} = P_o + P_{loss}$ → $P_{loss} = r_L I_{L_{avg}}^2$

$$I_{L_{avg}} = \frac{I_{L_{max}} + I_{L_{min}}}{2}, \quad I_{o_{avg}} = I_{D_{avg}} = (1-D) I_{L_{avg}}$$

$$V_o = \frac{V_s}{1-D}\left[\frac{1}{1+\frac{r_L}{R_o(1-D)^2}}\right]$$

• efficiency:

$$\eta = \frac{1}{1+\frac{r_L}{R(1-D)^2}}$$

• **D.C.M:**

$$V_o = \frac{V_s}{D_1}(D+D_1), \quad D_1 = \frac{2V_o L}{R V_s D T} \Rightarrow V_o = \frac{V_s}{2}\left[1+\sqrt{\frac{2D^2RT}{L}+1}\right]$$

** $\begin{cases} @\ C.C.M: & I_{L_{min}} \geq 0 \\ @\ D.C.M: & I_{L_{min}} < 0 \end{cases}$

※ Buck-Boost:

** $\begin{cases} \text{Boost}; & D > 0.5 \\ \text{Buck}; & D < 0.5 \end{cases}$

$P_{in} = P_{out}$.

• cct: V_s S L $\overleftarrow{D}$ C R

$$\boxed{D = \frac{|V_o|}{V_s + |V_o|}}, \quad V_o = \frac{-V_{in} D}{1-D}$$

$$I_{L_{\substack{max\\min}}} = I_{L_{avg}} \pm \frac{\Delta i_L}{2}$$

$$I_{L_{avg}} = \frac{V_{in} D}{R(1-D)^2}$$

$$\Delta i_L = (\Delta i_L)_{close}$$

$$I_{in_{avg}} = D I_{L_{avg}}$$

$$(\Delta i_L)_{close} = \frac{V_s D}{Lf}$$

$$(\Delta i_L)_{open} = \frac{V_o(1-D)}{Lf}$$

* with r_c:

$$\Delta V_o = \Delta i_c r_c; \quad \Delta i_c = I_{L_{max}}$$

$$L_{min} = \frac{1}{2} R (1-D)^2$$

$$C = \frac{(DT)^2}{R * Ripple.}$$

※ 2-Quadrant Converter:

- when S_1 closed: $V_{12} = DV_{in}$.

$$i_L = \frac{V_{12} - V_o}{R}$$

- when S_2 closed:
  - → find ΔV_L (when $V_{12} = 0$, By KVL)
  - then find $\Delta i_L = T(1-D)\frac{\Delta V_L}{L}$

- For the First Case:
  - Switch ON: $V_o = R i_o + L\frac{di_o}{dt} + V_a \qquad 0 < t \leq T_1$
  - Diode ON: $V_o = 0 = V_a + R i_o + L\frac{di_o}{dt} \qquad 0 \leq t \leq T - T_1$

$$\Rightarrow i_o(t) = \begin{cases} i_o(t) = \frac{V_s - V_a}{R}(1 - e^{-t/\tau}) + I_{min} e^{-t/\tau}, & 0 < t \leq T_1 \\ i_o(t) = \frac{-V_a}{R}(1 - e^{-t/\tau}) + I_{max} e^{-t/\tau}, & 0 < t \leq T - T_1 \end{cases}$$

$$D = \frac{T_{on}}{T} \qquad \tau = L/R$$

- MAX & MIN:

$$I_{max} = \frac{V_s}{R}\left[\frac{1 - e^{-T_1/\tau}}{1 - e^{-T/\tau}}\right] - \frac{V_a}{R}$$

$$I_{min} = \frac{V_s}{R}\left[\frac{e^{T_1/\tau} - 1}{e^{T/\tau} - 1}\right] - \frac{V_a}{R}$$

*Ripple:

$$\Delta I = I_{max} - I_{min}$$

$$V_{o_{avg}} = D V_s$$

$$I_{o_{avg}} = \frac{D V_s - V_a}{R}$$

$$V_{o_{RMS}} = \sqrt{D}\, V_s$$

※ 4-Quadrant Converter:

* $i_o(t) = \frac{V_s - V_a}{R}\left[1 - e^{-t/\tau}\right] + I_{min} e^{-t/\tau}$ for $0 < t \leq T_{on}$; $D \geq 0.5$

* $i_o(t) = -\left(\frac{V_s + V_a}{R}\right)\left[1 - e^{-t/\tau}\right] + I_{max} e^{-t/\tau}$ for $0 \leq t \leq T - T_{on}$; $D \leq 0.5$

* $i_o(t) = \frac{-V_a}{R}\left[1 - e^{-t/\tau}\right] + I_{max} e^{-t/\tau}$ for $\begin{cases} 0 \leq t \leq T_{on} ; & D < 0.5 \\ 0 \leq t \leq T - T_{on} ; & D \geq 0.5 \end{cases}$

- MAX & MIN:

$$I_{max} = \frac{V_s}{R}\left[\frac{1-e^{-T_{on}/\tau}}{1-e^{-T/\tau}}\right] - \frac{V_a}{R}$$

$$I_{min} = \frac{V_s}{R}\left[\frac{e^{T_{on}/\tau}-1}{e^{T/\tau}-1}\right] - \frac{V_a}{R}$$

* Ripple:

$$\Delta I = I_{max} - I_{min}$$

$$V_{o_{avg}} = V_s[2D-1]$$

$$I_{o_{avg}} = \frac{V_{avg} - V_a}{R}$$

※ Single Phase Inverter:

$\Rightarrow$ $D = 0.5$ $\quad \omega_o = 2\pi f_c \quad V_{o_{rms}} = V_s$

- Fourier Transform:

* $v_o(t) = \frac{4}{\pi} V_s \sum_{n=odd} \frac{1}{n}\sin(n\omega_o t)$ $\Rightarrow$ @ fund. freq. $(n=1)$: $\boxed{V_{o_{rms,1}} = 0.9\,V_s}$

* $i_o(t) = \frac{4}{\pi}\sum_{n=odd}\frac{V_s}{n Z_n}\sin(n\omega_o t - \phi_n)$ $\Rightarrow$ @ fund. freq. $(n=1)$: $I_{o_{rms,1}} = \frac{0.9V_s}{|Z_1|}$

$$\boxed{\begin{aligned} Z_n &= \sqrt{R^2 + (n\omega_o L)^2} \\ \phi_n &= \tan^{-1}\left[\frac{n\omega_o L}{R}\right]\end{aligned}}$$

* for $i_o(t)$:

$$i_o(t) = \frac{V_s}{R} - \left[\frac{V_s}{R} - I_{min}\right]e^{-t/\tau} \quad \text{for } t \leq T/2$$

$$i_o(t) = \frac{-V_s}{R} + \left[\frac{V_s}{R} + I_{max}\right]e^{-\frac{(t-T/2)}{\tau}} \quad \text{for } t \geq T/2$$

* Power: $P_1 = I_{o_{rms,1}} * V_{o_{rms,1}}$

- MAX & MIN:

$$I_{max} = -I_{min} = \frac{V_s}{R}\left[\frac{1-e^{\frac{-T/2}{\tau}}}{1+e^{\frac{-T/2}{\tau}}}\right]$$

※ Single Phase Inverter with Capacitors on the first leg:

$$V_{o_{rms}} = V_s/2 \quad , \quad I_{max} = -I_{min} = \frac{V_s/2}{R}\left[\frac{1-e^{\frac{-T/2}{\tau}}}{1+e^{\frac{-T/2}{\tau}}}\right]$$

* for $i_o(t)$:

$$i_o(t) = \frac{V_s/2}{R} - \left[\frac{V_s/2}{R} - I_{min}\right]e^{-t/\tau} \quad \text{for } t \leq \frac{T}{2}$$

$$i_o(t) = \frac{-V_s/2}{R} + \left[\frac{V_s/2}{R} + I_{max}\right]e^{-\frac{(t-\frac{T}{2})}{\tau}} \quad \text{for } t \geq \frac{T}{2}$$

※ Three Phase Inverter:

$S_1 \quad S_3 \quad S_5$
$S_4 \quad S_6 \quad S_2$

case(1): S_1, S_6, S_5. case(2): S_1, S_6, S_2. case(3): S_1, S_3, S_2.
case(4): S_4, S_3, S_2. case(5): S_4, S_3, S_5. case(6): S_4, S_6, S_5.

- **Line Voltages:**

case(1): $\boxed{V_{ab} = V_s,\ V_{bc} = -V_s,\ V_{ca} = 0}$
case(2): $\boxed{V_{ab} = V_s,\ V_{bc} = 0,\ V_{ca} = -V_s}$
case(3): $\boxed{V_{ab} = 0,\ V_{bc} = V_s,\ V_{ca} = -V_s}$
case(4): $\boxed{V_{ab} = -V_s,\ V_{bc} = V_s,\ V_{ca} = 0}$
case(5): $\boxed{V_{ab} = -V_s,\ V_{bc} = 0,\ V_{ca} = V_s}$
case(6): $\boxed{V_{ab} = 0,\ V_{bc} = -V_s,\ V_{ca} = V_s}$

- **Phase to Neutral Voltages:**

case(1): $\boxed{V_{an} = V_{cn} = \frac{V_s}{3},\quad V_{bn} = \frac{-2V_s}{3}}$

case(2): $\boxed{V_{an} = \frac{2V_s}{3},\quad V_{bn} = V_{cn} = \frac{-V_s}{3}}$

The same for other cases. (prove it).

- **Fourier Transform:**

$$V_{an} = \frac{2V_s}{\pi}\left[\sin\omega t + \frac{1}{3}\sin 3\omega t + \frac{1}{5}\sin 5\omega t + \cdots\right]$$
$$V_{bn} = \frac{2V_s}{\pi}\left[\sin(\omega t - 120) + \frac{1}{3}\sin 3(\omega t - 120) + \cdots\right]$$
$$V_{cn} = \frac{2V_s}{\pi}\left[\sin(\omega t + 220) + \frac{1}{3}\sin 3(\omega t + 120) + \cdots\right]$$

$$V_{ab} = \sqrt{3}\,\frac{2V_s}{\pi}\left[\sin(\omega t + 30) - \frac{1}{5}\sin 5(\omega t + 30) + \cdots\right]$$
$$V_{bc} = \sqrt{3}\,\frac{2V_s}{\pi}\left[\sin(\omega t - 90) - \frac{1}{5}\sin 5(\omega t - 90) + \cdots\right]$$
$$V_{ca} = \sqrt{3}\,\frac{2V_s}{\pi}\left[\sin(\omega t + 150) - \frac{1}{5}\sin 5(\omega t + 150) + \cdots\right]$$

- **Conduction Period:** cond. Period $= 3 * \frac{T}{6}$; depending on # of switches

- Without FWM: $V_{ab_{rms}} = \sqrt{\frac{2}{3}}\,V_s$
- With FWM: $V_{ab_{rms}} = \sqrt{\frac{2}{3}}\,V_s\sqrt{d}$ → $d = \frac{3N}{T}$, $x = \frac{dT}{3N}$

$V_{an_{rms}} = 0.47 V_s$

* For -ve Seq.:

Swap: S_1 with S_5
S_2 with S_4

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※ Single Phase H.W.R with R-load :

• cct: $V_S \xrightarrow[D]{(SCR)} R$

• **Average Output Voltage:**

→ in case $\beta > \pi$: $V_{o_{avg}} = \dfrac{V_m}{2\pi}\left[1+\cos\alpha\right]$

→ in case $\beta < \pi$: $V_{o_{avg}} = \dfrac{V_m}{2\pi}\left[\cos\alpha - \cos\beta\right]$

• **Average Output Current:** $I_{o_{avg}} = \dfrac{V_{o_{avg}}}{R}$

• **RMS Output Voltage:**

→ in case $\beta > \pi$: $V_{o_{rms}} = \dfrac{V_{s,rms}}{\sqrt{2}}\sqrt{1 - \dfrac{\alpha}{\pi} + \dfrac{\sin 2\alpha}{2\pi}}$

→ in case $\beta < \pi$: $V_{o_{rms}} = \dfrac{V_{s,rms}}{\sqrt{2}}\sqrt{\dfrac{\beta-\alpha}{\pi} - \left(\dfrac{\sin 2\beta - \sin 2\alpha}{2\pi}\right)}$

• **Voltage across the SCR:** $V_{SCR} = V_S - V_o$

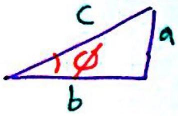
• **Average Power:**

→ in Case $\beta > \pi$: $P_{avg.} = \dfrac{V_m^2}{8\pi R}\left[2(\pi-\alpha)+\sin 2\alpha\right]$

→ in Case $\beta < \pi$: $P_{avg.} = \dfrac{V_m^2}{8\pi R}\left[2(\beta-\alpha)+\sin 2\alpha - \sin 2\beta\right]$

⇒ MAX Power @ $\alpha = 0$: $P_{max} = \dfrac{V_m^2}{4R}$

• **Power Factor:**



$I_{s_{1,max}} = \dfrac{V_{s_{1,max}}}{R}$ ... (1)

$a_1 = \dfrac{I_{s_{1,max}}}{2\pi}\left[-1+\cos 2\alpha\right]$ ... (2)

$b_1 = \dfrac{I_{s_{1,max}}}{4\pi}\left[2(\pi-\alpha)+\sin 2\alpha\right]$ ... (3)

$I_{1,rms} = \dfrac{C_1}{\sqrt{2}} = \dfrac{\sqrt{a_1^2+b_1^2}}{\sqrt{2}}$ ... (4)

$V_{rms} = \dfrac{V_{s,rms}}{\sqrt{2}}\sqrt{1-\dfrac{\alpha}{\pi}+\dfrac{\sin 2\alpha}{2\pi}}$ ... (5)

$I_{rms} = \dfrac{V_{rms}}{R}$ ... (6)

$\phi_1 = \tan^{-1}\left(\dfrac{a_1}{b_1}\right)$

$\cos\phi_1 = \dfrac{b_1}{c_1}$ ... (7)

$pf = \dfrac{I_{1,rms}}{I_{rms}}\cos\phi_1$ ... (8)

※ Single Phase F.W.R with R-load:

• cct: S_1 $\overset{+}{V_s}\,\overset{-}{}$ S_3 R S_4 S_2

• switch is a diode:

• case($V_s > 0$): S_1, S_2 (ON). $\Rightarrow V_o = V_s$

• case($V_s < 0$): S_3, S_4 (ON). $\Rightarrow V_o = -V_s$

$Pf_{H.W} = Pf_{F.W}$, $a_{1F.W} = 2a_{1H.W}$, $b_{1F.W} = 2b_{1H.W}$, $c_{1F.W} = 2c_{1H.W}$,

$V_{avg_{F.W}} = 2V_{avg_{H.W}}$

$P_{F.W} = 2P_{H.W}$

$V_{rms_{F.W}} = \sqrt{2}\, V_{rms_{H.W}}$

※ Single Phase H.W.R with RL-load:

• cct: V_s $\overrightarrow{D}$ R L

in case $R=0$:

$V_s(t) = V_m \sin\omega t$

$V_L(t) = V_m \cos(\omega t - \frac{\pi}{2})$

$I_L(t) = -I_m \cos(\omega t)$

$P_L(t) = -\frac{V_m I_m}{2}\sin(2\omega t)$

$P_{L_{avg}} = \text{Zero}$

• $\alpha \to \beta$:

$V_o(t) = V_s\,[u_\alpha - u_\beta]$

$$i_o(t) = \frac{V_{max}}{|Z|}\left[(u_\alpha - u_\beta)\sin(\omega t - \phi) + u_\alpha e^{\frac{-(\omega t - \alpha)}{\omega\tau}}\sin(\phi - \alpha)\right]$$

$\tau = L/R$; $Z = \sqrt{R^2 + (\omega L)^2}$; $\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

$V_{avg} = \frac{V_{s\,max}}{2\pi}[\cos\alpha - \cos\beta]$; $I_{o_{avg}} = \frac{V_{o_{avg}}}{R}$

※ Single Phase H.W.R with RL-load + Free Wheeling Diode:

• cct: V_s $\overrightarrow{SCR}$ R L Free wheeling diode.

• Output Voltage:
- $(\alpha \to \pi)$: $V_o = V_s$
- $(\pi \to \beta)$: $V_o = 0$

• Output Current:
- $(\alpha \to \pi)$: $i_o(t) = i_s(t)$
- $(\pi \to \beta)$: $i_o(t) = i_D(t)$

for $i_o(t)$:

$$i_o(t) = \begin{cases} i_s(t) = \frac{V_m}{|Z|}\left[\sin(\omega t - \phi) + e^{\frac{-(\omega t - \alpha)}{\omega\tau}}\sin(\phi - \alpha)\right] & ;\ \alpha \to \pi \\ i_D(t) = i_s(\pi)\, e^{\frac{-(\omega t - \alpha)}{\omega\tau}}\, u(\omega\tau - \pi) & ;\ \pi \to \beta \end{cases}$$

$i_{max} = i_s(\pi)$

$\Rightarrow$ $V_{o_{avg}} = \dfrac{V_m}{2\pi}\left[1+\cos\alpha\right]$, $I_{o_{avg}} = \dfrac{V_{o_{avg}}}{R}$

* Conduction Period $\equiv$ $\gamma = \alpha - \beta$

$\Rightarrow$ finding β : * if No assumptions given assume $\underline{<10\%}$ & $i_o(\beta) = 0.05\, i_s(\pi)$

$\Rightarrow$ find β from: $0.05 = e^{-\frac{(\beta-\pi)}{\omega\tau}}$; $\omega = 2\pi f$

$\tau = L/R$

※ Three Phase H.W.R with R-load :

$$V_{an} = V_m \sin\omega t$$
$$V_{bn} = V_m \sin(\omega t - 120^\circ)$$
$$V_{cn} = V_m \sin(\omega t + 120^\circ)$$

$a \rightarrow S_1$ if $S_1(ON) \Rightarrow V_{an} > V_{bn}, V_{cn}$

$b \rightarrow S_2$ if $S_2(ON) \Rightarrow V_{bn} > V_{an}, V_{cn}$

$c \rightarrow S_3$ if $S_3(ON) \Rightarrow V_{cn} > V_{an}, V_{bn}$

$(0 \rightarrow 30^\circ) \Rightarrow S_3$ ON $V_o = V_{cn}$

$(30^\circ \rightarrow 150^\circ) \Rightarrow S_1$ ON $V_o = V_{an}$

$(150 \rightarrow 270^\circ) \Rightarrow S_2$ ON $V_o = V_{bn}$

$$V_{o_{avg}}(3\phi) = 3V_{avg}(1\phi)$$
$$P_{avg}(3\phi) = 3P_{avg}(1\phi)$$
$$I_{avg}(3\phi) = \frac{V_{o_{avg}}(3\phi)}{R}$$

$$V_{o_{avg}}(3\phi) = \frac{3V_m}{2\pi}\left[\cos\alpha - \cos\beta\right]$$
$$P_{avg}(3\phi) = \frac{3V_m^2}{8\pi R}\left[2(\beta-\alpha) + \sin 2\alpha - \sin 2\beta\right]$$

P_{max} @ $\alpha = 0$.

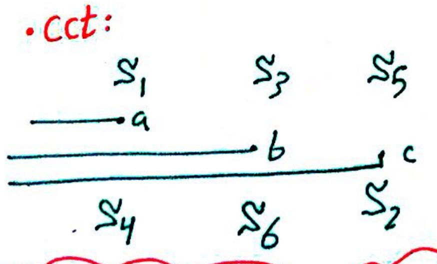
↳ if Line Voltage is given $\Rightarrow$ convert to phase.

α
$\alpha + 120$
$\alpha + 240$

$\beta = \alpha + 120^\circ$

※ Three Phase F.W.R :

• cct:



$V_{o_{avg}} = \dfrac{3\sqrt{3}\,|V_{an}|}{\pi}$; $I_{avg} = \dfrac{V_{o_{avg}}}{R}$

• $\alpha = 0$:

case	0→30	30→60	60→90	90→120	120→150	150→180
upper switch	C S_5	A S_1	A S_1	A S_1	A S_1	B S_3
Lower switch	B S_6	B S_6	B S_6	C S_2	C S_2	C S_2
V_o	V_{CB}	C_{AB}	V_{AB}	V_{AC}	V_{AC}	V_{BC}

- $\alpha = 30$: $\Rightarrow$ add 30° for all cases.
  $\Rightarrow$ V_o is the same shifted by 30°.

$$\Rightarrow \quad V_{o_{avg}} = \frac{3\sqrt{3}\,|V_{an}|}{\pi}\cos\alpha \rightarrow \text{same for } \alpha = 60.$$

- $\alpha = 90$: $\Rightarrow$

$$V_{o_{avg}} = \frac{3\sqrt{3}\,|V_{an}|}{\pi}\left[1 + \cos(\alpha + 60^\circ)\right]$$

- Summarize $V_{o_{avg}}$:

$$V_{o_{avg}} = \begin{cases} \dfrac{3\sqrt{3}\,|V_{an}|}{\pi}\cos\alpha & ; \ 0 \leq \alpha < 90^\circ \\ \dfrac{3\sqrt{3}\,|V_{an}|}{\pi}\left[1+\cos(\alpha+60^\circ)\right] & ; \ 90^\circ \leq \alpha < 120^\circ \\ \text{Zero} & ; \ \alpha \geq 120^\circ \end{cases}$$

※ AC/AC Converter:

- cct:

V_s — SCR / SCR — Load.

$$V_{o_{avg}} = \text{Zero}$$

$$V_{o_{rms}} = \frac{V_m}{\sqrt{2\pi}}\sqrt{(\pi - \alpha) + \frac{\sin 2\alpha}{2}}$$

* * *

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