IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

Charging Infrastructure

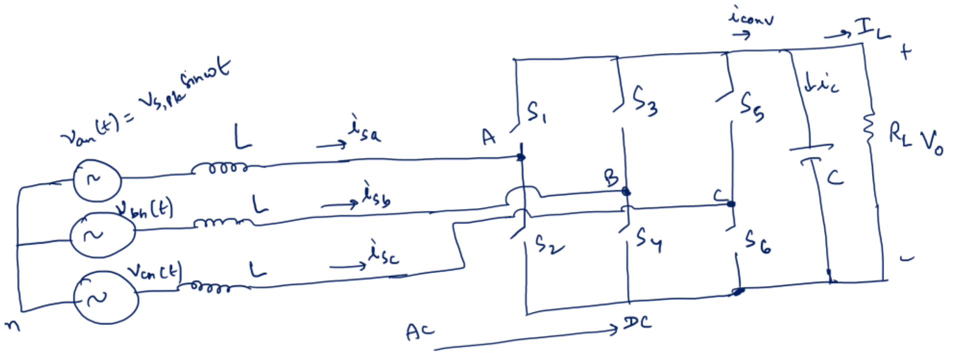
Lecture-24

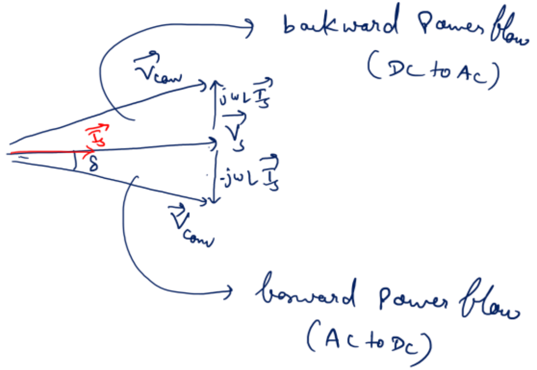
Three-phase AC-DC Converter-II

Dr. Apurv Kumar Yadav

Department of Electrical Engineering

Recap





$$v_{an}(t) = V_{s,pk} \sin\omega t$$
$$v_{bn}(t) = V_{s,pk} \sin(\omega t - 120)$$
$$v_{cn}(t) = V_{s,pk} \sin(\omega t - 240)$$

FEC

→ $(\omega L \cdot I_{s,pk}) < 10\%$ of $V_{s,pk}$

⇑ ensured

$$L = \sqrt{\frac{\left(\frac{m V_o}{2}\right)^2 - V_{s,pk}^2}{(2\pi f_s \cdot I_{s,pk})^2}}$$

→ m → modulation index → designer's choice (0.8 to 0.9)

$V_{s,pk}$ → specification

V_o → specification

f_s → line frequency given in specification

$I_{s,pk}$ → $\frac{P_L \times \sqrt{2}}{3 V_{ph,rms}}$ ⇐ assuming no loss in the Power Converter

→ the voltage drop across inductor (corresponding to fundamental) must be less than 10% of the $V_{s,pk}$

Sizing of switches

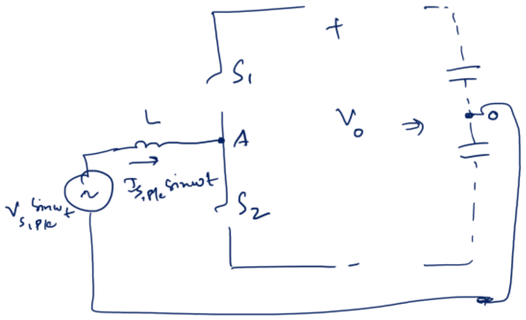
$D = \frac{1}{2} + \frac{v_m}{2V_c}$ (v_m → modulating signal; V_c → carrier signal) (from discussions in lec - 22)

⇒ In case of SPWM (Sinusoidal PWM) → $v_m = V_m \sin\omega t$

⇒ $D = \frac{1}{2} + \frac{V_m \sin\omega t}{2V_c}$

⇒ $D = \frac{1}{2} + \frac{m}{2}\sin\omega t$ $\left(m = \frac{V_m}{V_c}\right)$ → for S_1 switch

⇒ for S_2 switch ⇒ $1-D$ ⇒ $\frac{1}{2} - \frac{m}{2}\sin\omega t$



$T = 1/f_s$

$\Rightarrow \omega T = 2\pi$

If Mosfet with body diode is used to realize S_1 & S_2 switch

$$I_{rms,S_1} = \sqrt{\frac{1}{T}\int_0^T D\cdot(I_{s,pk}\sin\omega t)^2\, dt} \;;\quad I_{rms,S_2} = \sqrt{\frac{1}{T}\int_0^T \left(\frac{1}{2} - \frac{m}{2}\sin\omega t\right)(I_{s,pk}\sin\omega t)^2\, dt}$$

$$I_{rms,S_1} = \sqrt{\frac{1}{T}\int_0^T \left(\frac{1}{2} + \frac{m}{2}\sin\omega t\right)(I_{s,pk}\sin\omega t)^2\, dt}$$

If S_1 & S_2 switch is realized using IGBT with free wheeling diode

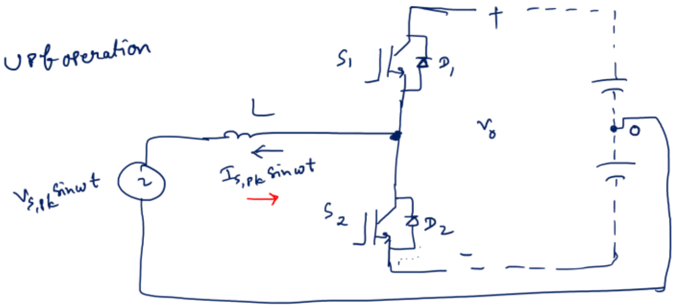
S_1 switch is in conduction for DT_s, during the positive half cycle

$D \rightarrow \frac{1}{2} + \frac{m}{2}\sin\omega t$

D_2 diode is in conduction for $(1-D)T_s$ duration → during positive half cycle

$1-D \rightarrow \frac{1}{2} - \frac{m}{2}\sin\omega t$

UPF operation



In positive half cycle, $v_s > 0$ $\quad T_s = 1/f_{sw}$

$\Rightarrow$ $S_1 \rightarrow DT_s$, $D_2 \rightarrow (1-D)T_s$ } in conduction

In negative half cycle, $v_s < 0$

$S_2 \rightarrow (1-D)T_s$, $D_1 \rightarrow DT_s$ } in conduction

$$I_{ave,switch,S_1} = \frac{1}{T}\int_0^{T/2}\left(\frac{1}{2} + \frac{m}{2}\sin\omega t\right) I_{s,pk}\sin\omega t \cdot dt$$

$$= \frac{1}{T} I_{s,pk}\left[\int_0^{T/2}\left[\frac{1}{2}\sin\omega t\, dt\right] + \int_0^{T/2}\left[\frac{m}{2}\sin^2\omega t \cdot dt\right]\right]$$

$$= \frac{I_{s,pk}}{2\pi}\left[1 + \frac{\pi m}{4}\right]$$

$$I_{rms,\,switch,\,S_1} = \sqrt{\frac{1}{T}\int_0^{T/2} D\,(I_{s,pk}\sin\omega t)^2\,dt} = \sqrt{\frac{1}{T}\int_0^{T/2}\left(\frac{1}{2}+\frac{m}{2}\sin\omega t\right)(I_{s,pk}\sin\omega t)^2\,dt} = \frac{I_{s,pk}}{2\sqrt{2}}\sqrt{1+\frac{8m}{3\pi}}$$

$$\Rightarrow I_{avg,\,diode,\,D_2} = \frac{1}{T}\int_0^{T/2}(1-D)\,I_{s,pk}\sin\omega t\cdot dt$$

$$= \frac{1}{T}\int_0^{T/2}\left(\frac{1}{2}-\frac{m}{2}\sin\omega t\right) I_{s,pk}\sin\omega t\cdot dt$$

$$= \frac{I_{s,pk}}{2\pi}\left[1-\frac{m\pi}{4}\right]$$

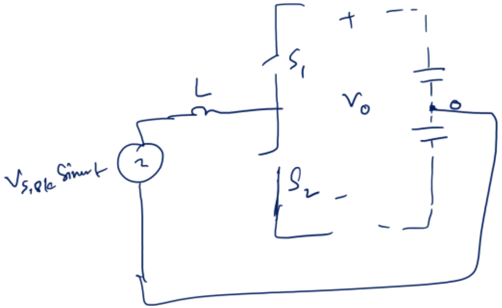
$$I_{rms,\,diode,\,D_2} = \sqrt{\frac{1}{T}\int_0^{T/2}(1-D)(I_{s,pk}\sin\omega t)^2\cdot dt}$$

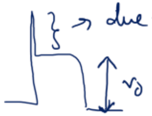
$$= \sqrt{\frac{1}{T}\int_0^{T/2}\left(\frac{1}{2}-\frac{m}{2}\sin\omega t\right)(I_{s,pk}\sin\omega t)^2\cdot dt}$$

$$I_{rms,\,diode,\,D_2} = \frac{I_{s,pk}}{2\sqrt{2}}\sqrt{1-\frac{8m}{3\pi}}$$

voltage stress across S_1 & S_2 = V_0

The voltage rating of S_1 & S_2 = $1.4V_0$ (40% → safety margin)



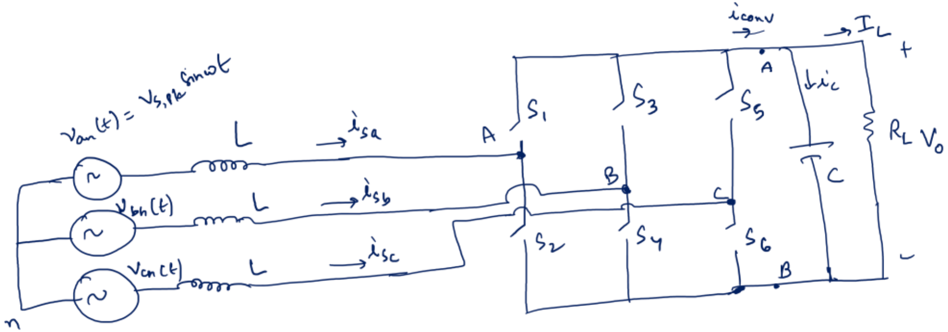


→ due to parasitic inductance of the loop = $L_{parasitic} \frac{di}{dt}$

→ voltage across switches S_1 & S_2

Sizing of Capacitance

⇒ The output power (at AB terminal)
$= V_o \cdot i_{conv}$



Input power $= V_{s,pk}\sin\omega t\, I_{s,pk}\sin\omega t$ → assuming upf operation
$+ V_{s,pk}\sin(\omega t-120) I_{s,pk}\sin(\omega t-120)$
$+ V_{s,pk}\sin(\omega t-240) I_{s,pk}\sin(\omega t-240)$

If there is loss-less converter
Apply Power balance
⇒ Input power = Output power

$$\Rightarrow V_o \cdot i_{conv} = V_{s,pk}\sin\omega t \cdot I_{s,pk}\sin\omega t + V_{s,pk}\sin(\omega t-120) I_{s,pk}\sin(\omega t-120) + V_{s,pk}\sin(\omega t-240) \cdot I_{s,pk}\sin(\omega t-240)$$

$$= V_{s,pk} I_{s,pk}\left(\sin^2\omega t + \sin^2(\omega t-120) + \sin^2(\omega t-240)\right)$$

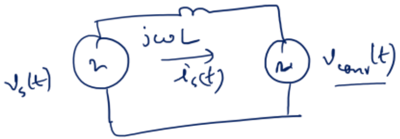
$$= V_{s,pk} I_{s,pk}\left(\frac{1-\cos 2\omega t}{2} + \frac{1-\cos(2\omega t-240)}{2} + \frac{1-\cos(2\omega t-480)}{2}\right)$$

$$= V_{s,pk} I_{s,pk}\left[\frac{3}{2} - \left(\underbrace{\cos 2\omega t + \cos(2\omega t-240) + \cos(2\omega t-120)}_{=0}\right)\right]$$

$\Rightarrow V_0 \cdot i_{conv} = \frac{3}{2} V_{s,pk} \cdot I_{s,pk}$

$\Rightarrow i_{conv} = \frac{3}{2V_0} V_{s,pk} \cdot I_{s,pk}$ $\longrightarrow$ there is absence of 2^{nd} line freq. component (only DC-component exist)

fundamental frequency



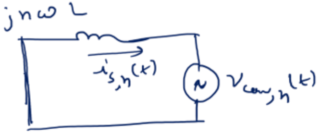
$\longrightarrow$ single-phase equivalent circuit

$i_s(t) = I_{s,pk} \sin \omega t$

$v_{conv}(t) \rightarrow$ fundamental component along with harmonics frequency component at side band of m_f $\left(m_f = \frac{f_c}{f_m}\right) \simeq$ carrier frequency

harmonic frequency component

The single phase equivalent circuit



$\Rightarrow i_{s,n}(t) = \frac{v_{conv,n}(t)}{jn\omega L}$

$\omega = 2\pi f_m$

$f_m = f_s$

$\omega = 2\pi f_s$

Thank You