

Inverters

Series Inverter: In a series inverter, the commutating elements L and C are connected in series with the load resistance R . The load resistance R can also be in parallel with C .

The value of L and C are such that those form an underdamped circuit i.e.

$$R^2 < \frac{4L}{C}$$

$$f = \left[\frac{1}{2 \left(\frac{T}{2} + T_{off} \right)} \right]$$

The frequency of output voltage,

Where, $\frac{T}{2}$ is the time period of oscillations.

T_{off} is the time gap between turn-off of one thyristor and turn-on of the second thyristor.

$$\frac{T}{2} = \frac{\pi}{\sqrt{\left(\frac{1}{LC} - \frac{R^2}{4L^2} \right)}}$$

The period of oscillation

Parallel Inverter: During the working of this inverter, capacitor C comes in parallel with the load via. the transformer, so this inverter is called a parallel inverter.

$$V_C = 2V_s \left[2 \exp \left(-\frac{n^2 t}{2RC} \right) - 1 \right]$$

Where, $n = \frac{N_2}{N_1}$ (turns ratio)

Commutating capacitance, $C = \frac{n^2 \cdot t_c}{4R \ln 2}$

Where, t_c = Circuit turn-off time

Bridge Inverter: Bridge circuits are commonly used in DC-AC conversion. Moreover, an output transformer is not essential in a bridge circuit.

1- ϕ Half Bridge Inverter- The output voltage volt $V_o = \sum_{n=1,3,5,\dots}^{\infty} \frac{2V_s}{n\pi} \sin n\omega t$

1- ϕ Full Bridge Inverter-

The output voltage
$$V_o = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi} \sin n\omega t$$

Where, n = order of harmonic

$\omega=2\pi f$, is frequency of the output voltage in rad/sec

Key Points

- The load impedance (Z_n) at frequency

$$Z_n = \left[R^2 + \left(n\omega L - \frac{1}{n\omega C} \right)^2 \right]^{-1/2}$$

- Phase angle, $(\phi_n), \phi_n = \tan^{-1} \left[\frac{n\omega L - \frac{1}{n\omega C}}{R} \right]$ rad
- Output current or load current at the instant of commutation

$$I_o = I_o = \frac{V_o}{Z_n} \text{ at } \omega t = \pi \text{ rad}$$

- Fundamental load power

$$(P_{o1}) P_{o1} = I_{o1}^2 R = V_{o1} \cdot I_{o1} \cos \phi_1$$

Amplitude Modulation Depth:

$$m_a = \frac{\hat{V}_m}{\hat{V}_c}$$

where V_m, V_c , are the modulating and carrier signal voltages, respectively.

For sinusoidal PWM, the amplitude modulation depth must be less than 1.0

Output Voltages:

$$\hat{V}_{k\ell 1} = m_a \frac{V_{DC}}{2}$$

$$V_{k\ell 1} = \frac{1}{2\sqrt{2}} m_a V_{DC}$$

the fundamental line-line voltage is given by

$$V_{LLO_1} = \frac{\sqrt{3}}{2\sqrt{2}} m_a V_{DC}$$

Available output voltage:

Assuming that the DC voltage is created using a diode rectifier and capacitor dc link, the maximum available DC voltage is given by

$$V_{DC} = \sqrt{2} V_{LLS}$$

where V_{LLS} is the line-line supply voltage. The maximum output using sinusoidal PWM ($m_a=1$) is

$$V_{LLO_1} = \frac{\sqrt{3}}{2\sqrt{2}} \sqrt{2} V_{LLS} = \frac{\sqrt{3}}{2} V_{LLS}$$

Resistive Load:

$$I(t) = \frac{V_s}{R}$$

where, V_s = DC voltage source

R = Load resistance

R-C (Resistive-Capacitive Load):

$$I(t) = \frac{V_s}{R} e^{-t/RC}$$

$$V_C(t) = V_s (1 - e^{-t/\tau})$$

Where, $V_C(t)$ = Voltage across capacitor at time t

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Initial rate of rise of capacitor voltage:

$$\left(\frac{dV_C}{dt} \right)_{t=0} = \frac{V_s}{RC} = \frac{V_s}{\tau} \quad \text{and time constant} \quad \tau = \frac{V_s}{\left(\frac{dV_C}{dt} \right)_{t=0}}$$

R-L Load:

$$I(t) = \frac{V_s}{R} (1 - e^{-Rt/L})$$

$$V_L = V_s e^{-Rt/L}; V_L = \text{Voltage across inductor}$$

$$\text{Initial rate of rise of current } \left(\frac{dI}{dt} \right)_{t=0} = \frac{V_s}{L}$$

L-C Load:

$$I(t) = I_p \sin \omega_0 t$$

$$\text{Where, } I_p = V_s \sqrt{\frac{C}{L}} \text{ and } \omega_0 = \frac{1}{\sqrt{LC}} = \text{resonant frequency}$$

$$\Rightarrow I(t) = V_s \sqrt{\frac{C}{L}} \sin \omega_0 t$$

Key Points

- Voltage across inductor, $V_L = V_s (\cos \omega_0 t)$
- Voltage across capacitor $V_C = V_s (1 - \cos \omega_0 t)$
- Conduction time, $t_1 = \pi \sqrt{LC} = \frac{\pi}{\omega_0}$

R-L-C Load:

$$\text{Characteristic equation, } S^2 + \frac{R}{L}S + \frac{1}{LC} = 0$$

$$\text{Damping factor, } \xi = \frac{R}{2L}$$

$$\text{Resonant frequency } \omega_0 = \frac{1}{\sqrt{LC}} \text{ rad/s}$$

Ringing frequency,

(or damped resonant frequency) $\omega_r = \sqrt{\omega_0^2 - \xi^2}$

Single Phase Half Wave Diode Rectifier:

with R Load:

- RMS value of output voltage,

$$V_{o \text{ rms}} = \frac{V_m}{2}$$

V_m = Maximum value of source voltage (V_S)

- Average value of output voltage, $V_{o \text{ DC}} = \frac{V_m}{\pi}$
- Power delivered $P = I_{o \text{ rms}}^2 \cdot R$

$I_{o \text{ rms}}$ = rms value of load current

- Input power factor $= \frac{\text{Power delivered to load}}{\text{Input } V_A}$

$$\text{Input PF} = \frac{V_{o \text{ rms}} \cdot I_{o \text{ rms}}}{V_S \cdot I_{o \text{ rms}}} = 0.707$$

With L load:

- Output current $I_o = \frac{V_m}{\omega L} (1 - \cos \omega t)$
- Maximum value of current $I_o = \frac{2X_m}{\omega L}$
- Average value of current $I_o = \frac{I_{\max}}{2}$

- RMS value of fundamental current $I_{1\text{rms}} = \frac{I_o}{\sqrt{2}}$
- Output voltage $V_o = V_m \sin \omega t = V_s$
- Average value of output voltage $V_o = 0$

With C Load:

- Output voltage $V_o = V_m \sin \omega t = V_s = V_c$
- Diode voltage $V_D = V_m (\sin \omega t - 1)$
- Output current $I_o = \omega C V_m \cos \omega t$
- Average value of diode voltage $V_D = V_m$
- RMS value of diode voltage $V_{\text{rms} D} = 1.225 V_m$

Class A Commutation (Load Commutation):

$$I(t) = V_s \sqrt{\frac{C}{L}} \sin \omega_0 t \quad \text{Conduction time of thyristor, } t_0 = \frac{\pi}{\omega_0} = \pi \sqrt{LC}$$

where, $\omega_0 = \text{resonant frequency} = \frac{1}{\sqrt{LC}}$

Class B Commutation:

- Resonant current $dI_C = -V_s \sqrt{\frac{C}{L}} \sin \omega_0 t$
- Peak resonant current $I_p = V_s \sqrt{\frac{C}{L}}$
- Voltage across capacitor $V_C = V_s \cos \omega_0 t$
- Circuit turn-off time for the main thyristor $(T_1); t_c = C \frac{V_{ab}}{I_o}$
- Reverse voltage across the main thyristor (T_1)

$$V_{sb} = V_s \cos \omega_0 (t_3 - t_2)$$

Where $t_3 = \text{time when the main thyristor is turned off}$

$t_2 = \text{time when auxiliary thyristor is turned off}$

and $\omega_0 (t_3 - t_2) = \sin^{-1} \left(\frac{I_o}{I_p} \right)$

Class C Commutation: When T_1 is turned on at $t = 0$

- The charging current $I_c = \frac{V_S}{R_2} \cdot e^{-t/R_2 C}$
- Voltage across capacitor $V_C(t) = V_S (1 - e^{-t/R_2 C})$

When T_1 is to be turned-off, T_2 is turned-on at T_1

- The charging current $I_c(t) = -\frac{2V_S}{R_1} \cdot e^{-t/R_1 C}$
- The voltage across capacitor, $V_C(t) = V_S [2e^{-t/R_1 C} - 1]$
- Maximum current through thyristor T_1 ,

$$I_{T_1(\max)} = V_S \left[\frac{1}{R_1} + \frac{2}{R_2} \right]$$

- Maximum current through thyristor T_2 ,

$$I_{T_2(\max)} = V_S \left[\frac{2}{R_1} + \frac{1}{R_2} \right]$$

Circuit turn-off time t_{c_1} for thyristor T_1

$$t_{c_1} = R_1 C \ln(2)$$

Circuit turn-off time t_{c_2} for thyristor T_2

$$t_{c_2} = R_2 C \ln(2)$$

Class D Commutation;

- Capacitor current

$$I_C = V_S \sqrt{\frac{C}{L}} \sin \omega_0 t$$

$$= I_p \sin \omega_0 t$$

- Circuit turn-off time for main thyristor (T_1)

$$t_c = C \frac{V_S}{I_0}$$

- Circuit turn-off time for auxiliary thyristor (T_A)

$$t_{c_1} = \frac{\pi}{2 \omega_0}$$
