Introduction to Power Electronics

Comprehensive Course on Power Electronics

Ankit Goyal • Lesson 1 • Nov 8, 2021

POWER ELECTRONICS

GATE WEITAGE 8-10 Marks

Books: MH Rashid, PS Bimbhra

↳ Theory ↳ Numericals

COURSE DURATION

80 TO 85 HOURS

① Handwritten notes will be provided

② Student assignment daily (to be solved every 4th lecture)

③ Every Sunday: weekly Quiz

No prerequisites required

POWER ELECTRONICS

	1 Marks	2 Marks	TOTAL
2006 KHARAGPUR	2	16	18
2014 SET - 1 KHARAGPUR	1	6	7
2014 SET - 2 KHARAGPUR	1	6	7
2014 SET - 3 KHARAGPUR	0	6	6
2021 BOMBAY	4	6	7

7-8 marks in GATE

Syllabus

Unit-1

→ other exams

POWER SEMICONDUCTOR DEVICES → 1 mark

- SWITCHES
- POWER DIODE
- POWER TRANSISTOR — BJT ✓, MOSFET ✓, IGBT ✓
- ** SCR (most imp) (family)
- THYRISTOR (GTO, RCT, Triac)

(toughest & most important unit)

PHASE CONTROLLED CONVERTERS

- 1 - Φ — HALF WAVE, FULL WAVE → UC (→ R, RL, RL+FD, L, RE, RLE), FC
- 3 - Φ — HALF WAVE, FULL WAVE → UC, SC, FC
- Source Indoctence
- Dual converter (ESE)

(Very easy & very important)

CHOPPERS

- BUCK
- BOOST
- BUCK-BOOST
- THYRISTOR COMMUTATION

INVERTERS (max (2-3 marks))

- 1- Phase
- 3- Phase
- PWM

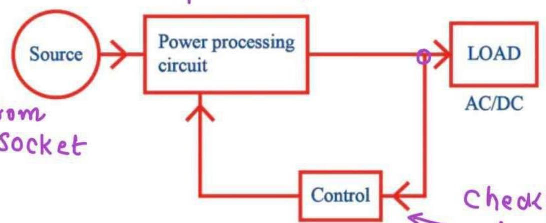
- Resonance Converter
- AC and DC Drive
- SMPS
- AC voltage controller → contains → ACVR, → Cyclo

$\left.\begin{array}{l}\text{Resonance Converter}\\ \text{AC and DC Drive}\\ \text{SMPS}\\ \text{AC voltage controller}\end{array}\right\}$ ESE

Basics of Power Electronics

- Power electronics is a technology associated with efficient conversion & control of electrical power semiconductor devices. Power processing circuit converts into different platform from similar platform.
- This acts as an interfacing circuit & it is also used to regulate or control of output. It contain power semiconductor devices.

Step down, AC → DC



from Socket

eg Laptop

Checks if o/p is at desired value & then control power ckt

Application of Power Electronics

① Switch mode power supply & UPS

② Energy conversion : dc → ac & ac → dc

③ Process control & Industrial automation

④ Transportation : electric vehicles / speed control

⑤ Welding, electroplating, Induction heating

⑥ HVDC & FACTS

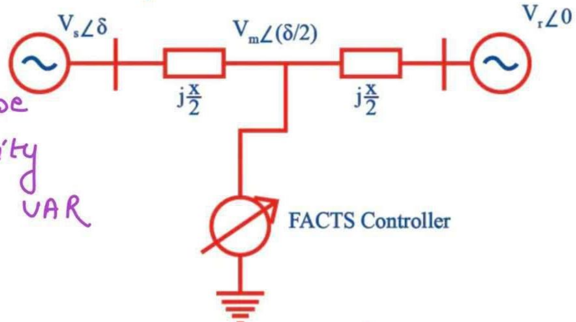
⑦ FAN Speed control

⑧ Adapters

Power Systems

(increasing steady state stability)

- we can increase P_{max} & hence increase steady state stability using SVC (Static VAR compensator).



- SVC is designed using FACTS controller.

Transportation

↳ Speed control of motor
  ↳ DC Drives : rectifiers, choppers
  ↳ AC Drives : inverters, AC voltage controller

↳ Battery operated vehicles
  ↳ interface battery to motor

Low Power Application:

↳ laptop chargers

↳ mobile chargers

↳ fan control

↳ diwali lighting

Renewable Energy Source (Medium Power Applications)

↳ Solar power

↳ has to be stored inside a battery (DC)

↳ to interface a solar power plant to power grid we need an Inverter.

Advantages

1. Power electronic circuits don't have any rotational parts, so that all losses in system will reduce. (rotational loss = 0)
2. When the losses are less, heat dissipation is also less, therefore it requires less cooling efforts (mounted on heat sink)
3. Power electronics equipment are compact in size
4. The closed loop control is possible with power electronic circuits

Disadvantages

1. Harmonics is major drawback of power electronics system. (switching)
2. Non-linear loads are the source of harmonics.
3. Harmonics is defined for non-sinusoidal periodic signals. In power electronics due to switching harmonics are generated.
4. The power semi-conductor devices will operate as switches, due to this switching action, all waveforms are non-sinusoidal & periodic in nature and such function can be expressed in terms of Fourier series

2: eg $i = I_m \sin\omega t$ $\quad v = 2i^2$: non-linear

$v = 2 I_m^2 \sin^2\omega t = I_m^2 (1 - \cos 2\omega t)$

$i : \omega$ $\quad v : 2\omega$ (harmonic)

Side effect of harmonics

1. Due to high frequency components in form of harmonics core losses in Induction Motor will increase and can damage the motor.
2. Input power factor of full control rectifier & AC voltage regulator is low due to harmonics.

Core loss: $P_{hys} \propto f$ $P_{eddy} \propto f^2$; at high freq both loss ↑, over heating

due to harmonics, torque contains harmonics, motor has noisy & vibrational operation.

3. If current contains harmonics, I_{rms} ↑, ohmic loss $I_{rms}^2 R$ ↑, η ↓

Fourier series

(Pre-requisite for power electronics)

- any periodic function which is not sinusoidal can be expressed as linear combination of harmonically related sinusoids.

$f(t)$: periodic with period (T)

fundamental frequency, $\omega_0 = 2\pi/T$

$$f(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos n\omega_0 t + b_n \sin n\omega_0 t)$$

- frequency of sine & cosine is multiple of ω_0

$$a_0 = \frac{1}{T} \int_{\langle T \rangle} f(t)\, dt$$

$\langle T \rangle \rightarrow$ integration over T

$$a_n = \frac{2}{T} \int_{\langle T \rangle} f(t) \cos n\omega_0 t\, dt \quad ; \quad b_n = \frac{2}{T} \int_{\langle T \rangle} f(t) \sin n\omega_0 t\, dt$$

Important points

① for even signals, $b_n = 0$ [same in 1^{st} & 2^{nd} quad or 3^{rd} & 4^{th} quad mirror image about y-axis]

② for odd signals, $a_0 = a_n = 0$ [symm about origin or symm in 1^{st} & 3^{rd} quad or symm in 2^{nd} & 4^{th} quad]

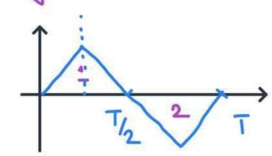
③ for half wave symmetry, n can only be odd

$a_n = b_n = 0$ if n = even ; $a_0 = 0$

only odd harmonics exist

[positive & negative cycle are same]

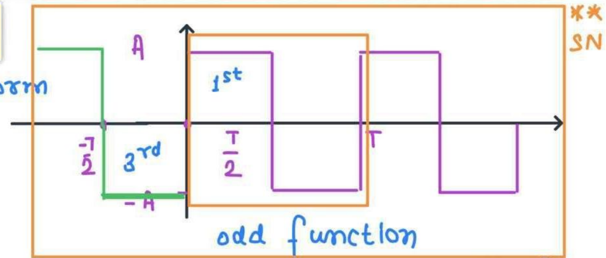
$$\boxed{f(t) = -f(t + T/2)}$$



2 is -ve of 1

Important Waveforms

① judge if the waveform is odd or even.



$a_0 = a_n = 0$: odd

$$b_n = \frac{2}{T}\int_0^T f(t)\sin n\omega_0 t\, dt \qquad \omega_0 = 2\pi/T$$

$$T\omega_0 = 2\pi$$

$$= \frac{2}{T}\left[\int_0^{T/2} A\sin n\omega_0 t\, dt + \int_{T/2}^{T} (-A)\sin n\omega_0 t\, dt\right]$$

$$= \frac{2A}{T(n\omega_0)}\left[\left(-\cos n\omega_0 t\right)_0^{T/2} + \left(\cos n\omega_0 t\right)_{T/2}^{T}\right]$$

$$b_n = \frac{2A}{2n\pi}\left[1 - \cos n\omega_0 T/2 + \cos n\omega_0 T - \cos n\omega_0 T/2\right]$$

$$= A/n\pi\left[2 - 2\cos n\pi\right]$$

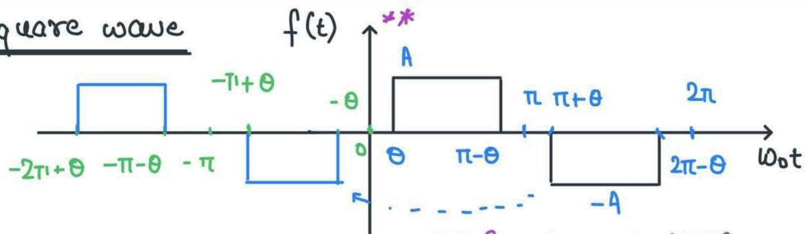
$$= 2A/n\pi\,(1 - \cos n\pi)$$

n = even $b_n = 0$ (Half wave symmetry)

n = odd, $\cos n\pi = -1$, $b_n = 4A/n\pi$

$$\boxed{f(t) = \sum_{n=1,3,5}^{\infty} 4A/n\pi \sin n\omega_0 t}$$ ** SN

② **Quasi-Square wave**



odd function + HWS

$$b_n = \frac{2}{2\pi}\left[\int_\theta^{\pi-\theta} A\sin n\omega_0 t\, d(\omega_0 t) + \int_{\pi+\theta}^{2\pi-\theta} (-A)\sin n\omega_0 t\, d(\omega_0 t)\right]$$

$$= \frac{A}{n\pi}\left[\left(-\cos n\omega_0 t\right)_\theta^{\pi-\theta} + \left(\cos n\omega_0 t\right)_{\pi+\theta}^{2\pi-\theta}\right]$$

$$b_n = A/n\pi\left[\cos n\theta - \cos(n\pi - n\theta) + \cos(2n\pi - n\theta) - \cos(n\pi + n\theta)\right]$$

$$b_n = A/n\pi\left[2\cos n\theta - 2\cos(n\pi - n\theta)\right]$$

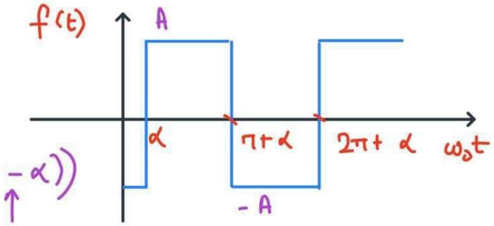
$$= 2A/n\pi\left[\cos n\theta - \cos(n\pi - n\theta)\right]$$

n = even, $b_n = 0$

n = odd, $b_n = 4A/n\pi \cos n\theta$

$$\boxed{f(t) = \sum_{n=1,3,5}^{\infty} 4A/n\pi \cos n\theta \sin n\omega_0 t}$$ ** SN

• square wave right shifted by an angle α



$$f(t) = \sum_{n=1,3,5}^{\infty} \frac{4A}{n\pi} \sin\left(n(\omega_0 t - \alpha)\right)$$

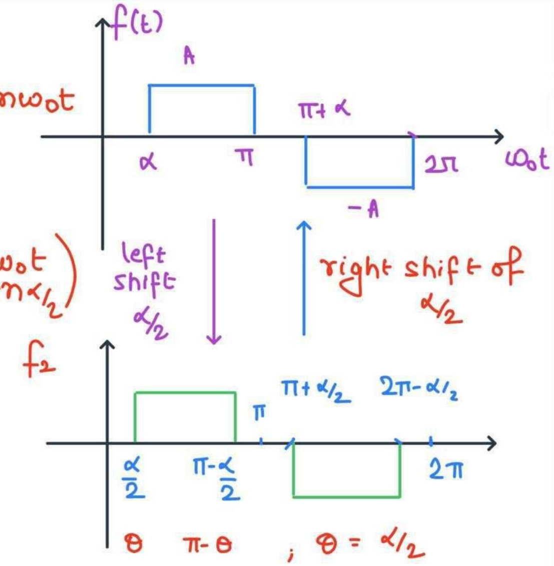
right shift by α

$$= \sum_{n=1,3,5}^{\infty} \frac{4A}{n\pi} \sin(n\omega_0 t - n\alpha)$$

④ for second waveform

$$f_2 = \sum_{n=1,3,5}^{\infty} \frac{4V}{n\pi} \cos\frac{n\alpha}{2} \sin n\omega_0 t$$

$$f(t) = \sum_{n=1,3,5}^{\infty} \frac{4V}{n\pi} \cos\frac{n\alpha}{2} \sin\left(n\omega_0 t - n\alpha/2\right)$$



⑤ $$f_1 = \sum_{n=1,3,5}^{\infty} \frac{4V}{n\pi} \sin n\omega_0 t$$

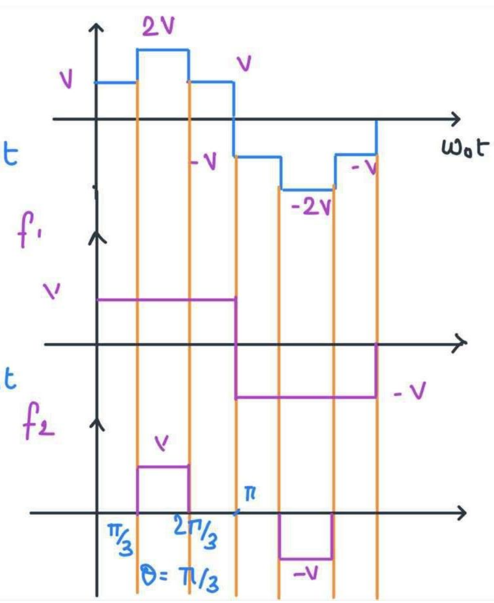
$$f_2 = \sum_{n=1,3,5}^{\infty} \frac{4V}{n\pi} \cos n\pi/3 \sin n\omega_0 t$$

$$f = f_1 + f_2$$

$$= \sum_{n=1,3,5}^{\infty} \frac{4V}{n\pi} (1 + \cos n\pi/3) \sin n\omega_0 t$$

$$= \sum_{n=6k\pm1}^{\infty} \frac{6V}{n\pi} \sin n\omega_0 t$$

$6k \pm 1 = 5, 7, 11, 13, 17, 19..$

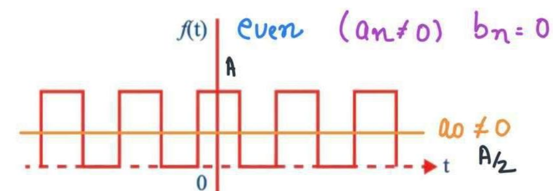


Question-01

The Fourier series expansion

$$f(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos n\omega t + bn \sin n\omega t$$

of the periodic signal shown below will contain the following nonzero terms

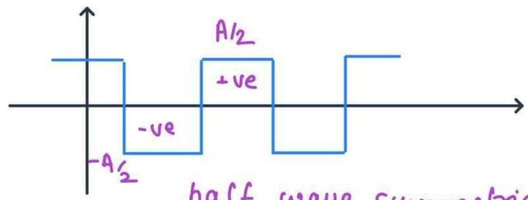


(a) a_0 and b_n, n = 1,3,5,… ∞
(b) a_0 and a_n, n = 1,2,3,… ∞
(c) a_0, a_n and b_n, n = 1,2,3,… ∞
(d) a_0 and a_n, n = 1,3,… ∞ ✓

Hidden half wave symmetry

↳ Whenever $a_0 \neq 0$

Subtract a_0 from waveform & then check for HWS



half wave symmetric

$n = 1, 3, 5, 7 \cdots, \infty$

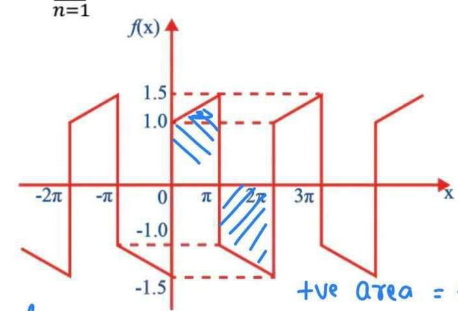
Question-02

$f(x)$, shown in the adjoining figure is represented by

$$f(x) = a0 + \sum_{n=1}^{\infty} [a_n \cos(nx) + bn \sin(nx)].$$

The value of a_0 is

(a) 0
(b) $\pi/2$
(c) π
(d) 2π



$a_0 = \frac{1}{2\pi} \int_{<2\pi>} f(x)\,dx$

$= \frac{\text{area in one period}}{2\pi}$

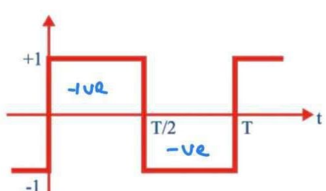
+ve area = -ve area

total area = 0

Question-03

The second harmonic component of the periodic waveform given the figure has an amplitude of

(a) 0
(b) 1
(c) $2/\pi$
(d) $\sqrt{5}$



half wave symmetric

⇓

only odd harmonics exist

⇓

2nd harmonic : even = 0

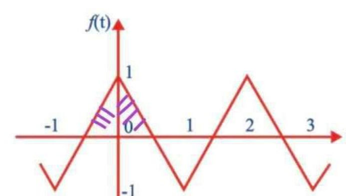
even: $b_n = 0$

odd: $a_n = 0$

HWS: $n = \text{odd}$

Question-04

Fourier series for the waveform, $f(t)$ shown in figure.



⇐ even signal ($b_n = 0$)

↳ only cosine terms are present

(a) $\frac{8}{\pi^2}\left[\sin(\pi t) + \frac{1}{9}\sin(3\pi t) + \frac{1}{25}\sin(5\pi t) + \dots\dots\dots\right]$

(b) $\frac{8}{\pi^2}\left[\sin(\pi t) - \frac{1}{9}\cos(3\pi t) + \frac{1}{25}\sin(5\pi t) + \dots\dots\dots\right]$

(c) $\frac{8}{\pi^2}\left[\cos(\pi t) + \frac{1}{9}\cos(3\pi t) + \frac{1}{25}\cos(5\pi t) + \dots\dots\dots\right]$

(d) $\frac{8}{\pi^2}\left[\cos(\pi t) - \frac{1}{9}\sin(3\pi t) + \frac{1}{25}\sin(5\pi t) + \dots\dots\dots\right]$