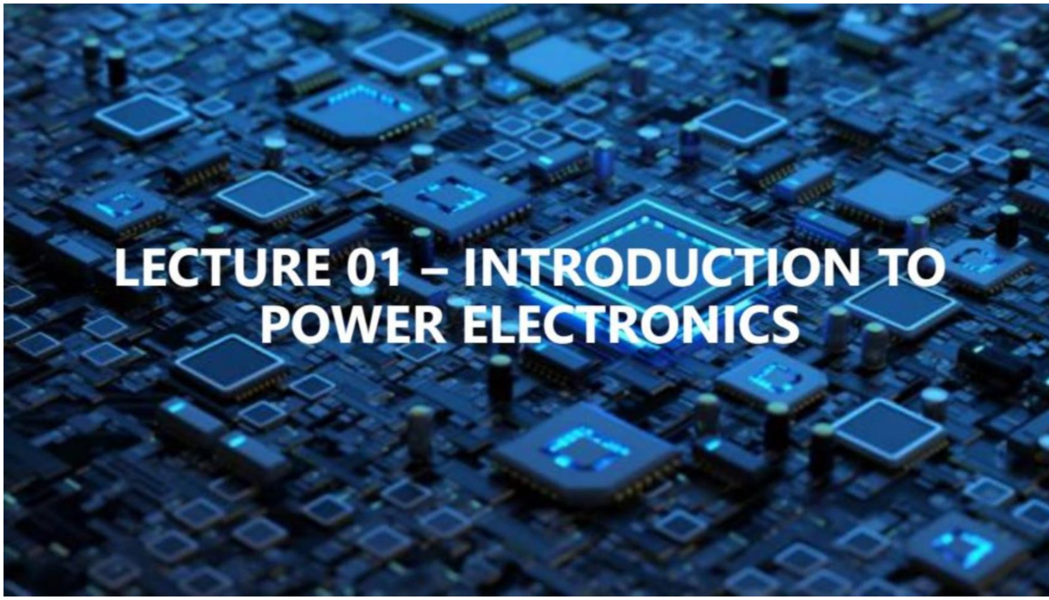
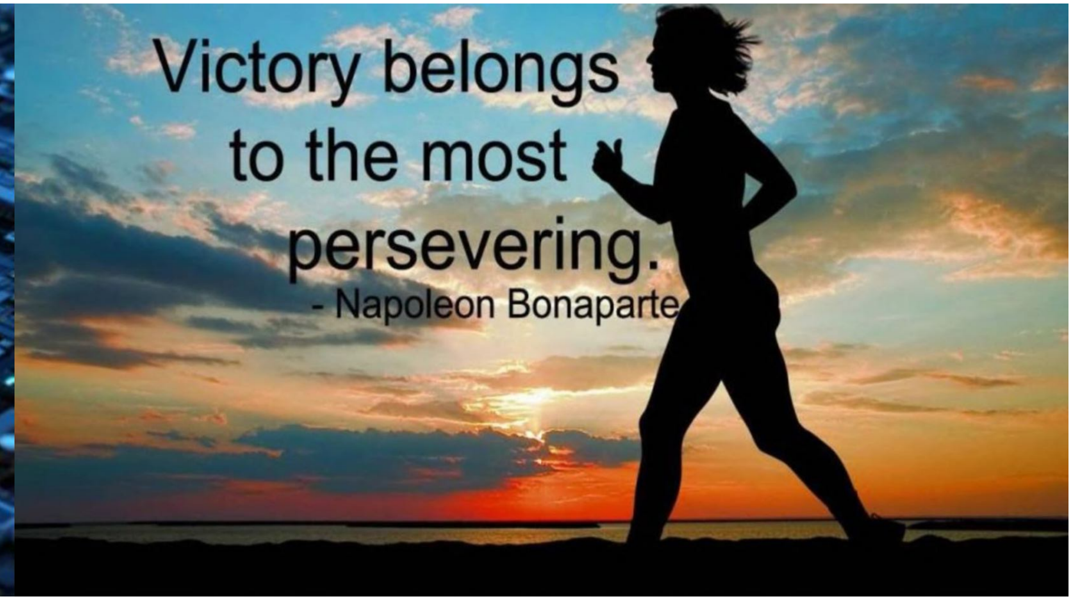



**POWER ELECTRONICS**

**GATE WEITAGE** 8-10 Marks

**Books: MH Rashid, PS Bimbhra**

Theory Problems

**COURSE DURATION**

**80 TO 85 HOURS**

| Exam Year | 1 Mark Question | 2 Mark Question | Total Mark |
|---|---|---|---|
| 2011 | 2 | 3 | 8 |
| 2012 | 2 | 3 | 8 |
| 2013 | 0 | 7 | 14 |
| 2014 Set-1 | 2 | 3 | 8 |
| 2014 Set-2 | 1 | 3 | 7 |
| 2014 Set-3 | 0 | 3 | 6 |
| 2015 Set-1 | 2 | 3 | 8 |
| 2015 Set-2 | 2 | 3 | 8 |
| 2016 Set-1 | 2 | 4 | 10 |
| 2016 Set-2 | 3 | 4 | 11 |
| 2017 Set-1 | 4 | 2 | 8 |
| 2017 Set-2 | 4 | 3 | 10 |
| 2018 | 3 | 3 | 9 |
| 2019 | 2 | 4 | 10 |
| 2020 | 4 | 2 | 8 |
| 2021 | 1 | 3 | 7 |
| 2022 | 3 | 4 | 11 |
| 2023 | 2 | 2 | 6 |
| 2024 | 3 | 4 | 11 |

## Weightage of Power Electronics in Recent Years

| CHAPTER | 2024 | 2023 | 2022 | 2021 | 2020 | 2019 | 2018 | AVERAGE |
|---|---|---|---|---|---|---|---|---|
| POWER SEMICONDUCTOR DEVICES | 1 | 2 | 1 | 0 | 1 | 0 | 1 | 0.86 |
| RECTIFIERS | 2 | 2 | 6 | 1 | 3 | 5 | 4 | 3.29 |
| DC-DC CONVERTERS | 3 | 2 | 2 | 4 | 2 | 4 | 4 | 3 |
| INVERTERS | 2 | 0 | 2 | 2 | 1 | 1 | 0 | 1.14 |
| AC VOLTAGE CONTROLLERS | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0.29 |
| DRIVES | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0.29 |
| **TOTAL** | **11** | **6** | **11** | **7** | **8** | **10** | **9** | **8.86** |

## Weightage of Power Electronics by IIT Roorkee

| CHAPTER | 2009 | 2017 Set 1 | 2017 Set 2 |
|---|---|---|---|
| POWER SEMICONDUCTOR DEVICES | 4 | 1 | 0 |
| RECTIFIERS | 2 | 2 | 5 |
| DC-DC CONVERTERS | 2 | 2 | 2 |
| INVERTERS | 2 | 2 | 3 |
| AC VOLTAGE CONTROLLERS | 0 | 0 | 0 |
| DRIVES | 0 | 0 | 0 |
| **TOTAL** | **10** | **7** | **10** |

## Syllabus

### POWER SEMICONDUCTOR DEVICES

- SWITCHES
- POWER DIODE
- POWER TRANSISTOR
  - BJT
  - MOSFET
  - IGBT
- SCR
- THYRISTOR

### PHASE CONTROLLED CONVERTERS

- 1 - Φ
  - HALF WAVE
  - FULL WAVE
- 3 - Φ
  - HALF WAVE
  - FULL WAVE
- Source Inductance
- Dual converter (ESE)

## CHOPPERS

- BUCK
- BOOST
- BUCK-BOOST
- THYRISTOR COMMUTATION

## INVERTERS

- 1- Phase
- 3- Phase
- PWM
- Resonance Converter
- AC and DC Drive
- SMPS
- AC voltage controller

(Resonance Converter, AC and DC Drive, SMPS, AC voltage controller: ESE)

## Schedule

## Power Electronic Switches

| Date | Lecture Number | Lecture Title | Complete Title | Time |
|---|---|---|---|---|
| 07-Oct-24 | Lecture-01 | Introduction to Power Electronics | Lecture-01: Introduction to Power Electronics | 6:00 AM |
| 07-Oct-24 | Lecture-02 | Power Semiconductor Switches Part-01 | Lecture-02: Power Semiconductor Switches Part-01 | 8:00 AM |
| 08-Oct-24 | Lecture-03 | Power Semiconductor Switches Part-02 | Lecture-03: Power Semiconductor Switches Part-02 | 6:00 AM |
| 08-Oct-24 | Lecture-04 | Power Diode Part-01 | Lecture-04: Power Diode Part-01 | 8:00 AM |
| 09-Oct-24 | Lecture-05 | Power Diode Part-02 | Lecture-05: Power Diode Part-02 | 6:00 AM |
| 09-Oct-24 | Lecture-06 | Assignment Discussion | Lecture-06: Assignment Discussion | 8:00 AM |
| 10-Oct-24 | Lecture-07 | Power Transistors Part-01 | Lecture-07: Power Transistors Part-01 | 6:00 AM |
| 10-Oct-24 | Lecture-08 | Power Transistors Part-02 | Lecture-08: Power Transistors Part-02 | 8:00 AM |
| 11-Oct-24 | Lecture-09 | Thyristors Part-01 | Lecture-09: Thyristors Part-01 | 6:00 AM |
| 11-Oct-24 | Lecture-10 | Thyristors Part-02 | Lecture-10: Thyristors Part-02 | 8:00 AM |
| 12-Oct-24 | Lecture-11 | Thyristors Part-03 | Lecture-11: Thyristors Part-03 | 6:00 AM |
| 12-Oct-24 | Lecture-12 | Assignment Discussion | Lecture-12: Assignment Discussion | 8:00 AM |
| 13-Oct-23 | | | | |
| 14-Oct-23 | Lecture-13 | Thyristors Part-04 | Lecture-13: Thyristors Part-04 | 6:00 AM |
| 14-Oct-23 | Lecture-14 | Thyristors Part-05 | Lecture-14: Thyristors Part-05 | 8:00 AM |

# Rectifiers

| Date | Lecture Number | Lecture Title | Complete Title | Time |
|---|---|---|---|---|
| 15-Oct-23 | Lecture-15 | Introduction to Phase Controlled Converters | Lecture-15: Introduction to Phase Controlled Converters | 6:00 AM |
| 15-Oct-23 | Lecture-16 | Single Phase Rectifier Part-01 | Lecture-16: Single Phase Rectifier Part-01 | 8:00 AM |
| 16-Oct-23 | Lecture-17 | Single Phase Rectifier Part-02 | Lecture-17: Single Phase Rectifier Part-02 | 6:00 AM |
| 16-Oct-23 | Lecture-18 | Assignment Discussion | Lecture-18: Assignment Discussion | 8:00 AM |
| 17-Oct-23 | Lecture-19 | Single Phase Rectifier Part-03 | Lecture-19: Single Phase Rectifier Part-03 | 6:00 AM |
| 17-Oct-23 | Lecture-20 | Single Phase Rectifier Part-04 | Lecture-20: Single Phase Rectifier Part-04 | 8:00 AM |
| 18-Oct-23 | Lecture-21 | Single Phase Rectifier Part-05 | Lecture-21: Single Phase Rectifier Part-05 | 6:00 AM |
| 18-Oct-23 | Lecture-22 | Single Phase Rectifier Part-06 | Lecture-22: Single Phase Rectifier Part-06 | 8:00 AM |
| 19-Oct-23 | Lecture-23 | Single Phase Rectifier Part-07 | | 6:00 AM |
| 19-Oct-23 | Lecture-24 | Three Phase Rectifiers Part-01 | Lecture-24: Three Phase Rectifiers Part-01 | 8:00 AM |
| 20-Oct-23 | | | | |
| 21-Oct-23 | Lecture-25 | Assignment Discussion | Lecture-25: Assignment Discussion | 6:00 AM |
| 21-Oct-23 | Lecture-26 | Three Phase Rectifiers Part-02 | Lecture-26: Three Phase Rectifiers Part-02 | 8:00 AM |
| 22-Oct-23 | Lecture-27 | Three Phase Rectifiers Part-03 | | 6:00 AM |
| 22-Oct-23 | Lecture-28 | Three Phase Rectifiers Part-04 | Lecture-28: Three Phase Rectifiers Part-04 | 8:00 AM |
| 23-Oct-23 | Lecture-29 | Line Commutated Inverters and Source Inductance | Lecture-29: Line Commutated Inverters and Source Inductance | 6:00 AM |
| 23-Oct-23 | Lecture-30 | Assignment Discussion | Lecture-30: Assignment Discussion | 8:00 AM |

# DC-DC Converters

| Date | Lecture Number | Lecture Title | Complete Title | Time |
|---|---|---|---|---|
| 24-Oct-23 | Lecture-31 | Step Down Choppers | Lecture-31: Step Down Choppers | 6:00 AM |
| 24-Oct-23 | Lecture-32 | Buck Converters | Lecture-32: Buck Converters | 8:00 AM |
| 25-Oct-23 | Lecture-33 | Boost and Buck Boost Converters | Lecture-33: Boost and Buck Boost Converters | 6:00 AM |
| 25-Oct-23 | Lecture-34 | Thyristor Commutation Part-01 | Lecture-34: Thyristor Commutation Part-01 | 8:00 AM |
| 26-Oct-23 | Lecture-35 | Assignment Discussion | Lecture-35: Assignment Discussion | 6:00 AM |
| 26-Oct-23 | Lecture-36 | Thyristor Commutation Part-02 & Types of Choppers | Lecture-36: Thyristor Commutation Part-02 & Types of Choppers | 8:00 AM |

# Inverters

| Date | Lecture Number | Lecture Title | Complete Title | Time |
|---|---|---|---|---|
| 27-Oct-23 | Lecture-37 | Single Phase Inverters | Lecture-37: Single Phase Inverters | 6:00 AM |
| 27-Oct-23 | Lecture-38 | Single Phase Inverters and Current Source Inverters | Lecture-38: Single Phase Inverters and Current Source Inverters | 8:00 AM |
| 28-Oct-23 | Lecture-39 | Three Phase Inverters | Lecture-39: Three Phase Inverters | 6:00 AM |
| 28-Oct-23 | Lecture-40 | Assignment Discussion | Lecture-40: Assignment Discussion | 8:00 AM |
| 29-Oct-23 | Lecture-41 | Pulse Width Modulation | Lecture-41: Pulse Width Modulation | 6:00 AM |

# Miscellaneous

| Date | Lecture Number | Lecture Title | Complete Title | Time |
|---|---|---|---|---|
| 29-Oct-23 | Lecture-42 | AC Voltage Regulators | Lecture-42: AC Voltage Regulators | 8:00 AM |
| 30-Oct-23 | Lecture-43 | Dual Converters & Cycloconverters | Lecture-43: Dual Converters & Cycloconverters | 6:00 AM |
| 30-Oct-23 | Lecture-44 | AC & DC Drives Part-01 | Lecture-44: AC & DC Drives Part-01 | 8:00 AM |
| 31-Oct-23 | Lecture-45 | AC & DC Drives Part-02 | Lecture-45: AC & DC Drives Part-02 | 6:00 AM |
| 31-Oct-23 | Lecture-46 | Resonant Converters and SMPS | Lecture-46: Resonant Converters and SMPS | 8:00 AM |
| 03-Nov-23 | Lecture-47 | Assignment Discussion | Lecture-47: Assignment Discussion | 6:00 AM |

## Strategy

→ Fourier Series

1. No Pre-requisite (Basic of semi conductor)
2. No need of standard books
3. No need to make complete notes
4. Make hand written short notes

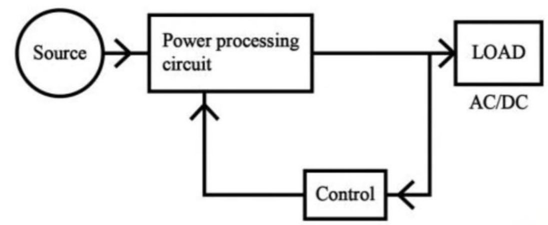
1. DPP
2. Structured Notes
3. Weekly Quiz
4. Doubts
5. Shorts notes

→ Attend live classes daily
→ Make short notes
→ Resolve class questions
→ Practice DPP

→ Attempt weekly Quiz
→ Solve PYQs
(weekend)

## 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.




- feed back controller controls the operation of power semi conductor devices based on deviation of actual output from desired output.

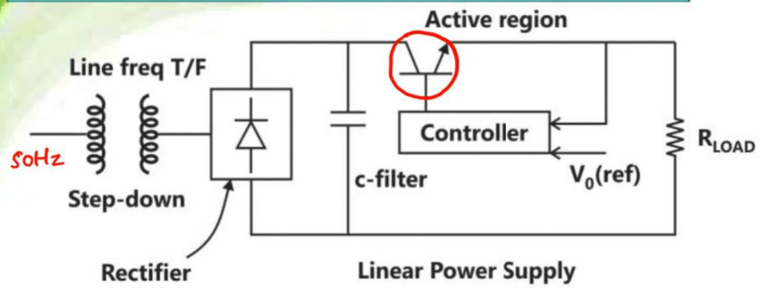
## Basics of Power Electronics

- Feedback controller compares the output of power processing ckt with a desired reference & error between 2 values is minimized.
- Error is minimized by controlling the switching of power semiconductor devices.
- Firing circuits: Circuits that are used to trigger a power semiconductor device.

## Power Electronics Vs Analog Electronics

- In power conversion process, low energy loss and high $\eta$ is desirable because
  i. Cost of wasted energy
  ii. Difficult to remove heat generated due to wasted energy
- Other important aspect is reduction in size, weight and cost
- These objective cannot to met by linear ICs where active device operates in linear region and line frequency. T/F is used for isolation.
  ↳ 50Hz

## Power Electronics Vs Analog Electronics




- ➢ In power electronics, device is made to operate as a switch at high switching frequency (300 kHz–1MHz) & high frequency T/F is used for isolation & hence size & weight of T/F reduces

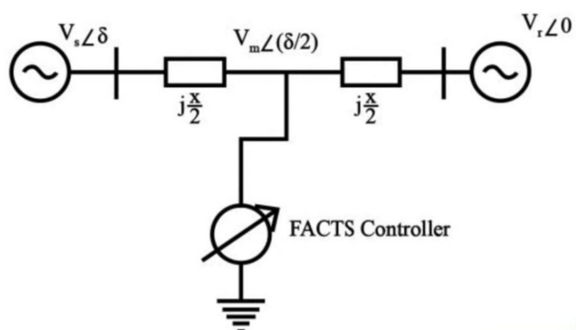
Such a supply is called switch mode power supply (SMPS)

## Application of Power Electronics

1. Switch mode power supply and uninterrupted power supply.
2. Energy conversion: in a conventional pump, motor rotates at constant speed o/p of pump is controlled by valve & constant power is drawn from supply.
3. If pump is controlled by variable speed drive then power i/p can be controlled
3. Process control & factory automation
4. Transportation: EVs use battery chargers & PE → ac→dc
5. Welding, electroplating & induction heating
6. HVDC (rectifier at sending end & inverter at receiving end)
7. Home automation

## Power Systems

- ➢ By use of FACTS controller we can perform reactive power compensation which can help control voltage & improve stability.




## Transportation

- ➢ Electric Vehicle → dc motor

→ Battery chargers (ac → dc)

→ Motor Control [Chopper Controlled DC motor]

→ controls the dc voltage based on duty cycle of switch

- ➢ Electric locomotives
- ➢ Speed control dc motor → Armature voltage control (control Vt) → below $N_{base}$

→ field control (control $I_f$) → above $N_{base}$

## Low Power Application

- ➢ Trimmers: Battery + dc motor
- → Battery charge: ac→dc converter
- → Speed control of dc motor

- ➢ Laptop & mobile chargers (ac → dc)

- ➢ Fan Speed control (triac : ac → ac)

## Renewable Energy Source (Medium Power Applications)

- ➢ Solar power converter
- → Solar cells produce dc power
- → dc power must be converted to ac power before connecting to grid
- → Inverters are required for dc→ac conversion

## Advantages

1. Power electronic circuits don't have any rotational parts, so that all losses in system will reduce. (no friction & windage losses).
2. When the losses are less, heat dissipation is also less, therefore it requires less cooling efforts.
3. Power electronics equipment are compact in size.
4. The closed loop control is possible with power electronic circuits.
5. High reliability & less maintenance.
6. Long life due to absence of moving parts.

## Disadvantages

1. Harmonics is major drawback of power electronics system.
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

## Question

**Why harmonics are undesirable?**

→ Degrade quality of electric power supply. → waveform becomes non-sinusoidal → $I_{rms} = [I_1^2 + I_2^2 + I_3^2 \dots]^{1/2}$

→ Increased losses in distribution system. ($I_{rms}\uparrow, I_{rms}^2 R \uparrow$)

→ Overload in neutral conductor → neutral carries zero sequence or triplex harmonic current — for balanced system $I_n = 0$

→ Vibrations & premature ageing of generator, motor, T/F

→ Increase in noise level

→ Distortion in supply can disturb operation of sensitive load.

→ Disturbance in telephone or comm. line (zero sequence) → triplen harmonics

→ Increase in m/c core losses. ($P_h \propto f$, $P_e \propto f^2$)

## Fourier Series (Trigonometric)

➢ Any periodic function can be expressed as a linear combination of harmonically related sinusoids

(Frequency are a multiple of a fundamental frequency)

$x(t) = a_0 + \sum_{n=1}^{\infty}[a_n \cos n\omega_0 t + b_n \sin n\omega_0 t]$ $\omega = n\omega_0$ , $\omega_0$ = fund. Freq.

$a_0 =$ average value or dc component $= 1/T \int_{\langle T \rangle} x(t)dt$

$a_n = \frac{2}{T}\int_{\langle T \rangle} x(t)\cos n\omega_0 t dt$

$b_n = \frac{2}{T}\int_{\langle T \rangle} x(t)\sin n\omega_0 t dt$

$\langle T \rangle$: integral over one period
$0 \to T$
$-T/2 \to T/2$
$-T/4 \to 3T/4$
etc

## Fourier Series (Trigonometric)

** SN

(a) for an even function

→ wave form symmetric about vertical axis

$x(-t) = x(t)$

$b_n = 0$

(b) for an odd function

→ waveform is symmetric about origin ($1^{st}$ & $3^{rd}$ quad / $2^{nd}$ & $4^{th}$ quad)

$x(-t) = -x(t)$

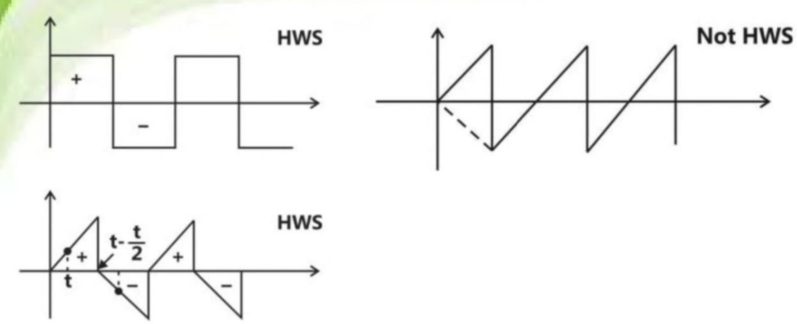
$a_0 = a_n = 0$

(c) half wave symmetry

→ $x(t + T/2) = -x(t)$

only odd harmonics exist $a_n, b_n = 0 \ \forall \ n =$ even

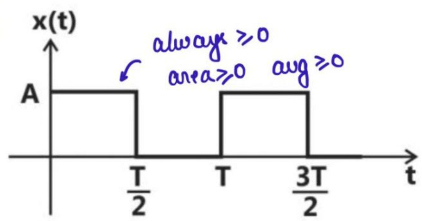
## Fourier Series (Trigonometric)

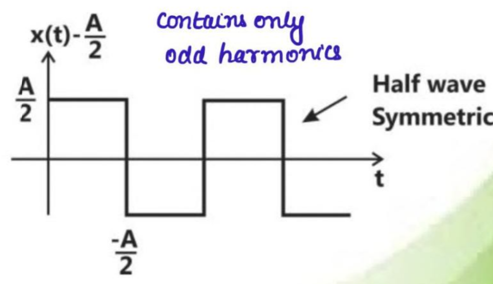



➢ -ve half cycle should be mirror image of +ve half cycle about time axis.

## Hidden Symmetry

- For functions having non-zero average value, subtract average value from functions i.e shift graph downwards by an amount equal to average & then check for HWS



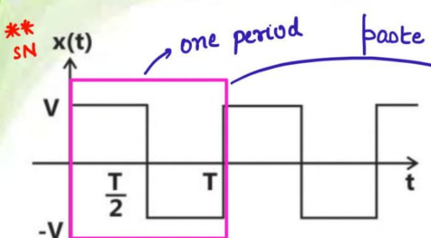

$avg = \frac{A \times \frac{T}{2}}{T} = \frac{A}{2}$

## Side effect of harmonics

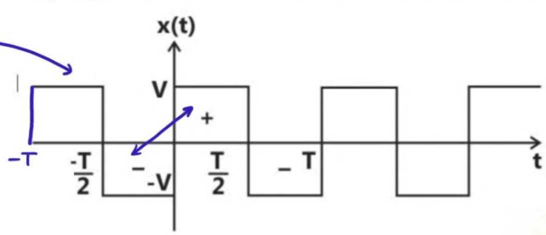
1. Due to high frequency components in form of harmonics core losses in Induction Motor will increase and can damage the motor.
2. Input power factor of full control rectifier & AC voltage regulator is low due to harmonics.

## Important Waveforms

** SN




To judge odd or even draw on –ve side of t-axis




$b_n = \frac{2}{T} \int_{<T>} x(t) \sin n\omega_0 t \, dt$

$b_n = 0 \quad \forall \; n = \text{even}$

Odd function & half wave symmetric

$a_0 = a_n = 0$

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

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

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

$\omega_0 = 2\pi/T \qquad \omega_0 T = 2\pi$

$b_n = \frac{2V}{2n\pi} \left[ 1 - \cos n\pi + \underset{=1}{\cos 2n\pi} - \cos n\pi \right]$

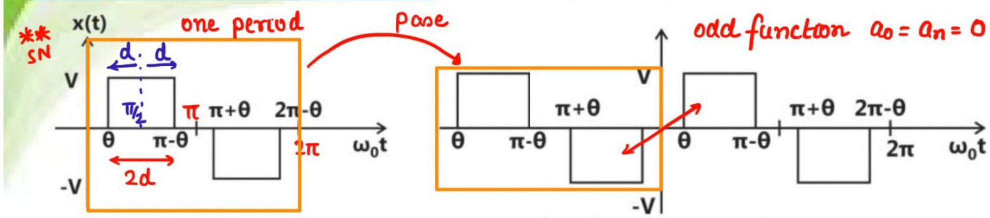
$= \frac{2V}{n\pi} (1 - \cos n\pi) = \begin{cases} 4V/n\pi & n = \text{odd} \\ 0 & n = \text{even} \end{cases}$

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

** SN

# Important Waveforms

Quasi - Square wave




half wave symmetric

$b_n = 0 \quad \forall \; n = \text{even}$

$$b_n = \frac{2}{2\pi}\int_0^{2\pi} x(t)\sin n\omega_0 t \, d(\omega_0 t)$$

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

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

$$= \frac{V}{n\pi}\left[\cos n\theta - \cos(n\pi - n\theta) + \cos(2n\pi - n\theta) - \cos(n\pi + n\theta)\right]$$

$$= \frac{V}{n\pi}\left[2\cos n\theta - 2\cos(n\pi - n\theta)\right]$$

$$= \frac{2V}{n\pi}\left(\cos n\theta - \cos(n\pi - n\theta)\right)$$

$$= \begin{cases} 0 & n = \text{even} \\ \frac{4V}{n\pi}\cos n\theta & n = \text{odd} \end{cases}$$

**SN

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

**SN

$$\boxed{\begin{aligned} 2d &= \text{pulse width} \\ 2d &= (\pi - \theta) - \theta = \pi - 2\theta \\ d &= \pi/2 - \theta \qquad \theta = \pi/2 - d \end{aligned}}$$

$$\cos n\theta = \cos(n\pi/2 - nd)$$

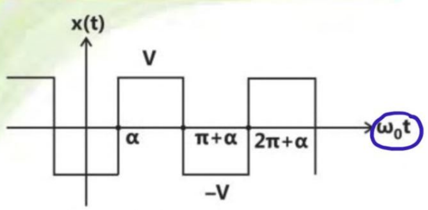
$$= \cos n\pi/2 \cos nd + \sin n\pi/2 \sin nd$$

$\cos n\pi/2 = 0 \quad n = \text{odd}$

**SN

$$\boxed{x(t) = \sum_{n=1,3,5}^{\infty} \frac{4V}{n\pi} \sin n\pi/2 \sin nd \sin n\omega_0 t}$$

# Important Waveforms




Shifted square wave

right shifted by $\alpha$

$x(t - t_0)$ : right shift

$x(t + t_0)$: left shift

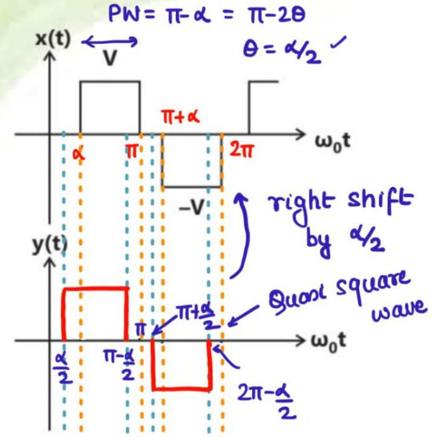
$$x(t) = \sum_{n=1,3,5}^{\infty} \frac{4V}{n\pi} \sin(n(\omega_0 t - \alpha))$$

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

# Important Waveforms

PW = $\pi - \alpha = \pi - 2\theta$

$\theta = \alpha/2$




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

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

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