TSTE19 Power Electronics

- Lecture 15
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- ISY/EKS

Outline

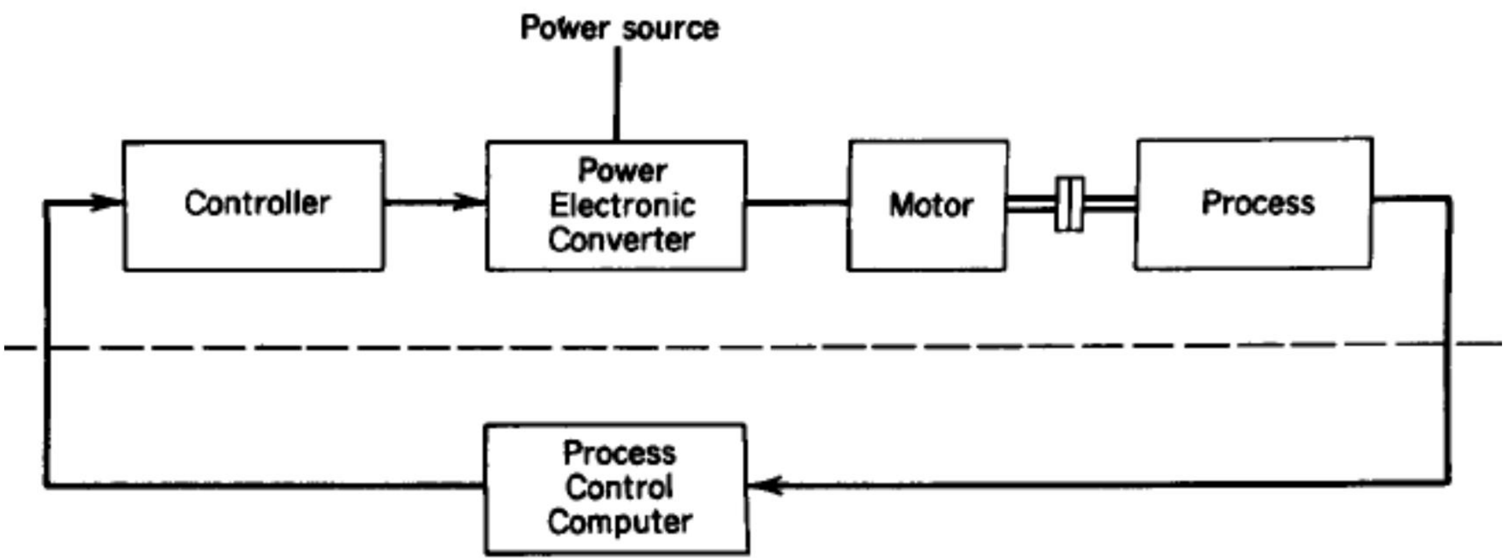
- Motor drives
- Harmonics

Motor drives

- Details on electrical motor principles, design, and control found in other course
  - TSFS04 Electrical Drives
- Motor control is a common application of power electronics
- Three major types
  - DC motors
  - Induction motors
  - Synchronous motors

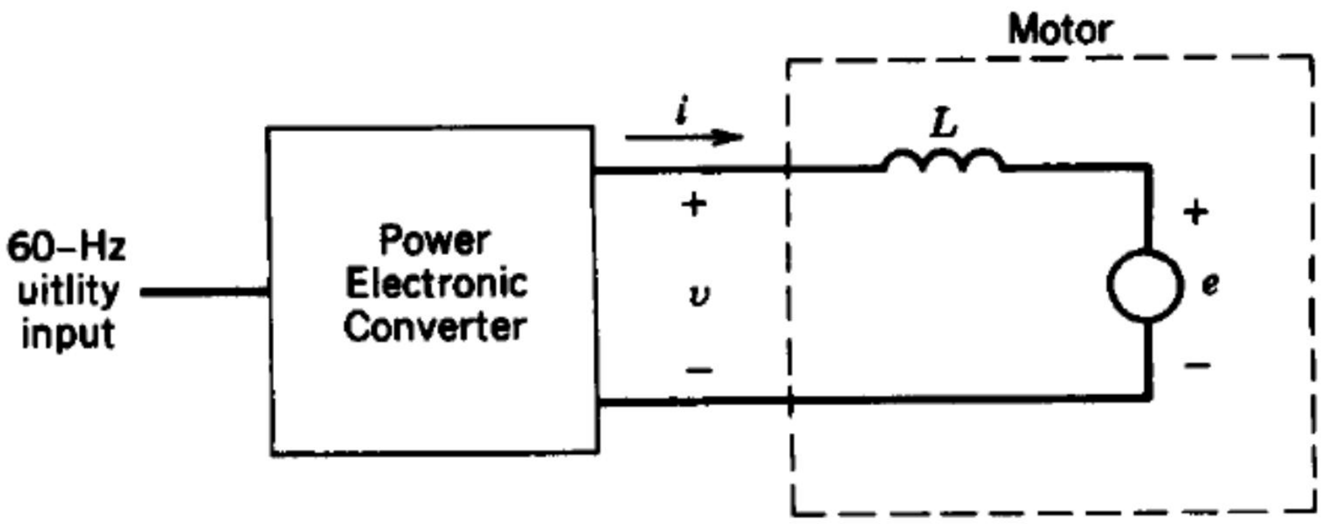
Electric motor control structure

- Process may return speed and/or position as well as temperature or other sensor values
  - Motor speed are sometimes not interesting, e.g. in ventilation systems



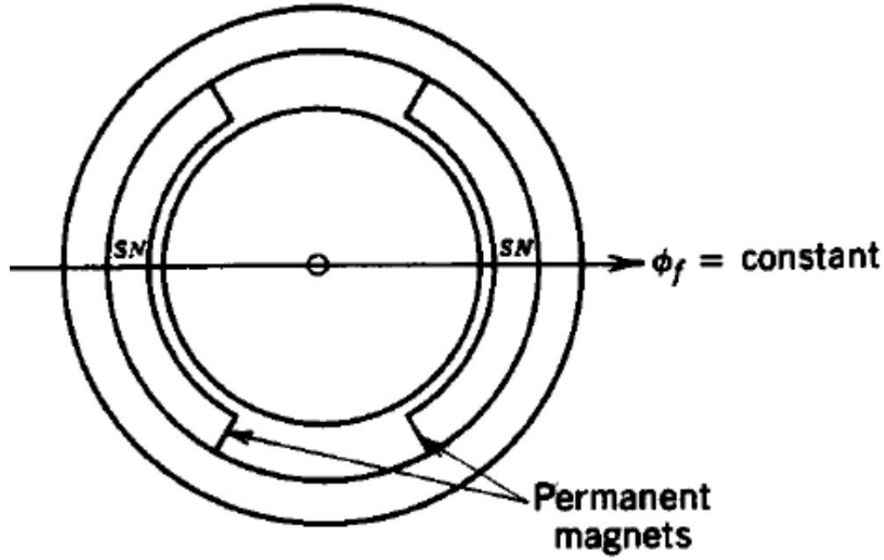
Simplified circuit of a drive

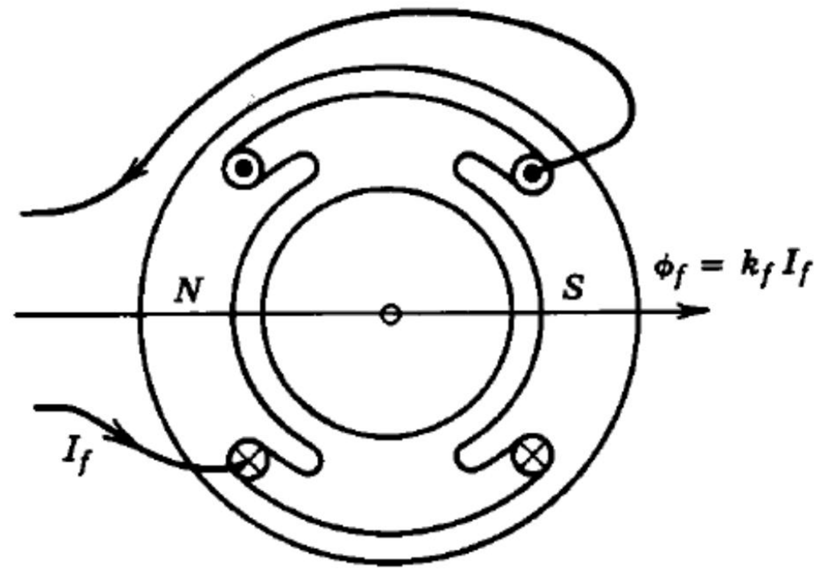
- Counter-emf e increase linearly with motor speed
- Voltage rating of power electronic converter defined by maximum motor speed
- Current rating defined by the mechanical torque

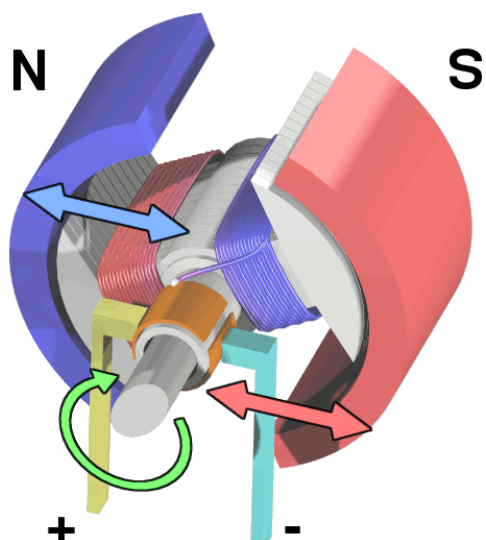


DC-Motor drive

- Stator field by permanent magnets or field windings
- Rotor contains armature winding
  - Handles the electrical power
  - Connected through carbon brushes

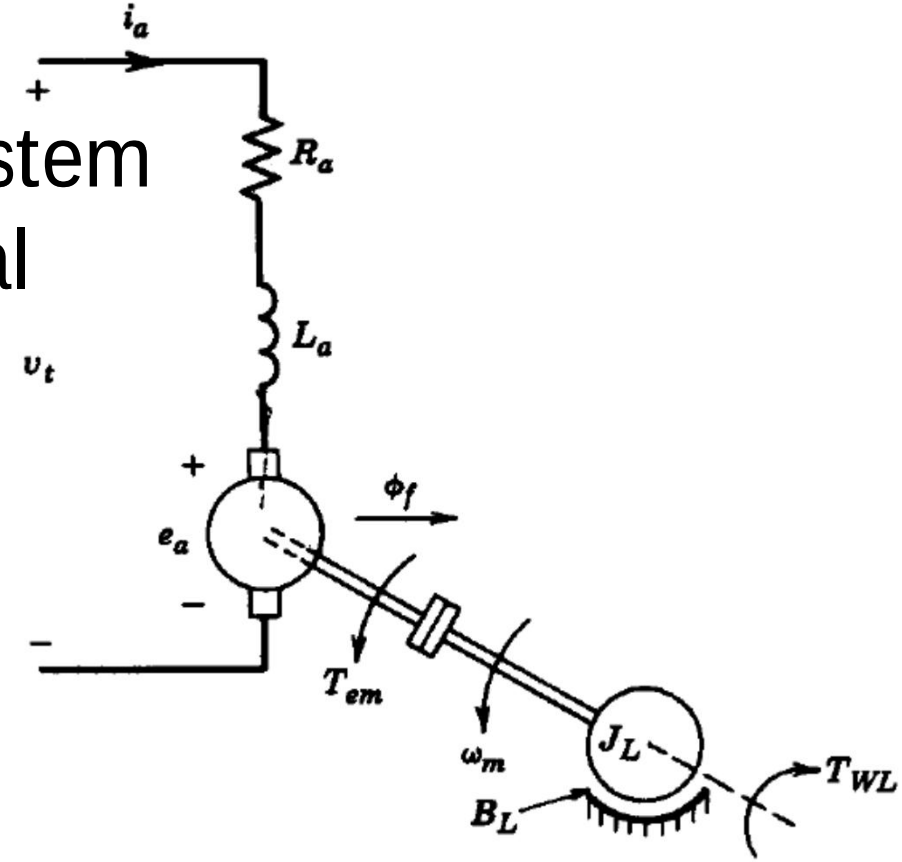






DC motor equivalent circuit

- Includes mechanical system modeled as an electrical circuit
- T_{em} = Electromagnetic torque
- ω_m = speed
- J, B equivalent inertia and damping



DC-motor equivalent

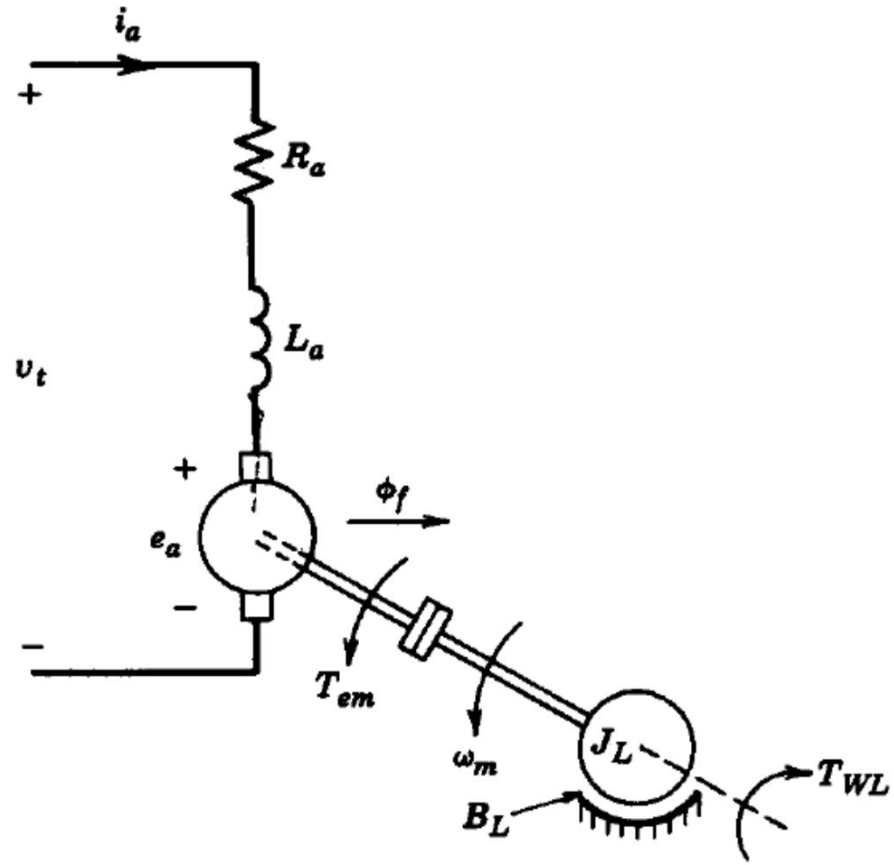
- $T_{em} = k_t \phi_f i_a,$
- $P_m = \omega_m T_{em} = k_t \phi_f \omega_m i_a$
- $e_a = k_e \phi_f \omega_m$
- $P_e = e_a i_a = k_e \phi_f \omega_m i_a$

Steady state:

- $P_e = P_m \Rightarrow k_e = k_t$

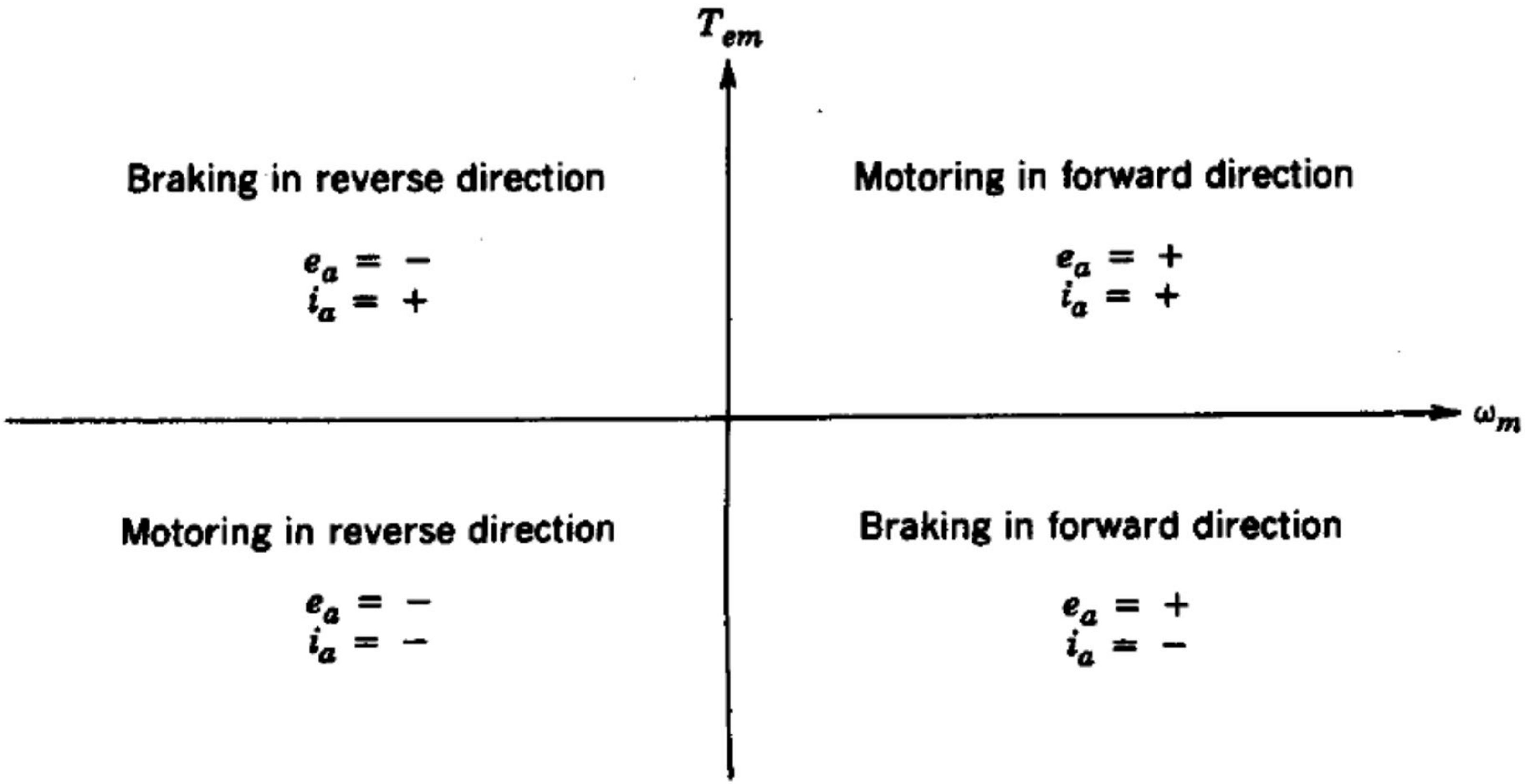
Equivalent circuit

- $v_t = e_a + R_a i_a + L_a \frac{di_a}{dt}$



Operation of DC motor

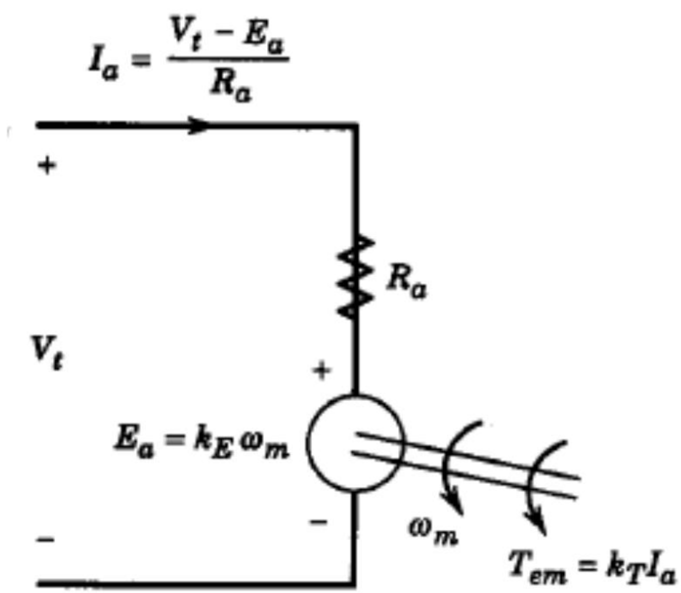
- Can be reversed as well as act as a generator

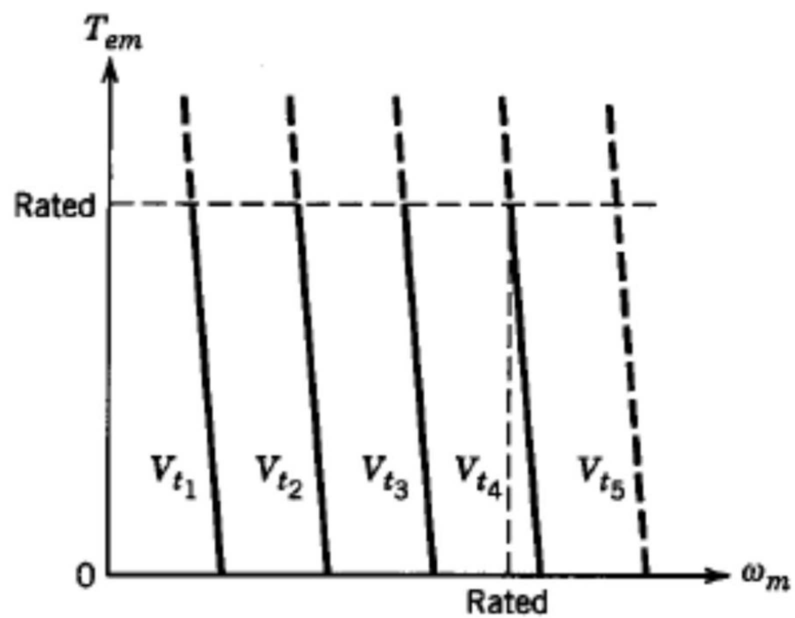


Control of DC motor

- Control of V_t controls torque T_{em}

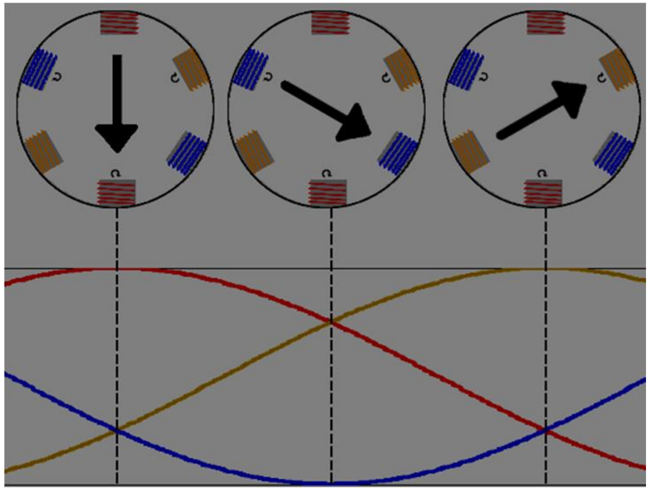
- $T_{em} = k_T I_a$
  - $k_T = k_t \phi_f$
- $E_a = k_E \omega_m$
  - $k_E = k_e \phi_f$
- $V_t = E_a + R_a I_a$





Induction motor drive

- No carbon brushes
- Rotating stator magnetic field
  - Requires three or more phases
  - Fixed speed
- Induces a magnetic field in the rotor winding
- Synchronous speed
  $\omega_s = 2(2*\pi*f)/p = 2\omega/p$
  - p = number of poles in motor
  - $n_s = 60 \cdot \frac{\omega_s}{2\pi} = \frac{120}{p} f$ [rpm]
- Slip speed $\omega_{sl} = \omega_s - \omega_r$
  - Slip $s = (\omega_s - \omega_r) / \omega_s$



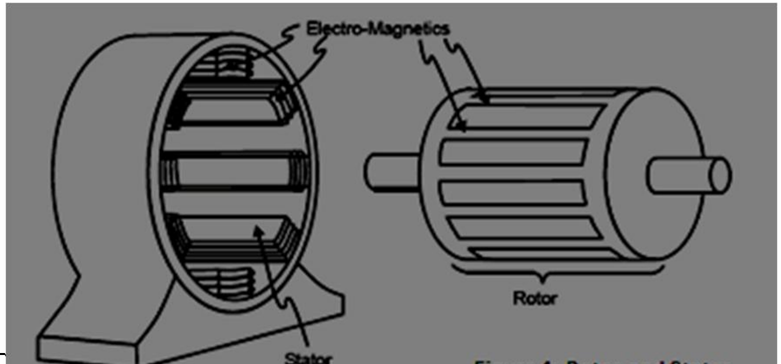
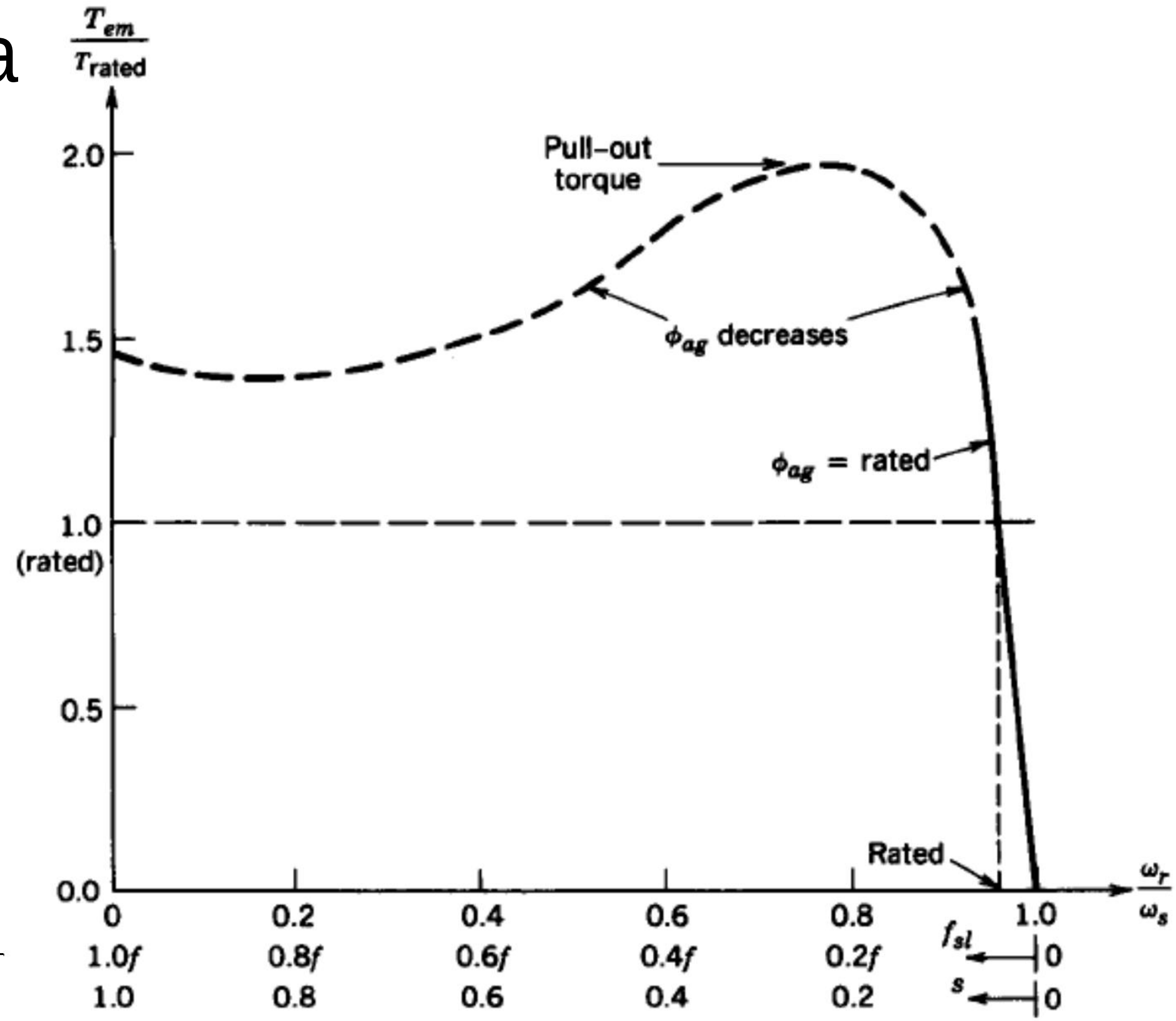


Figure 4: Rotor and Stator

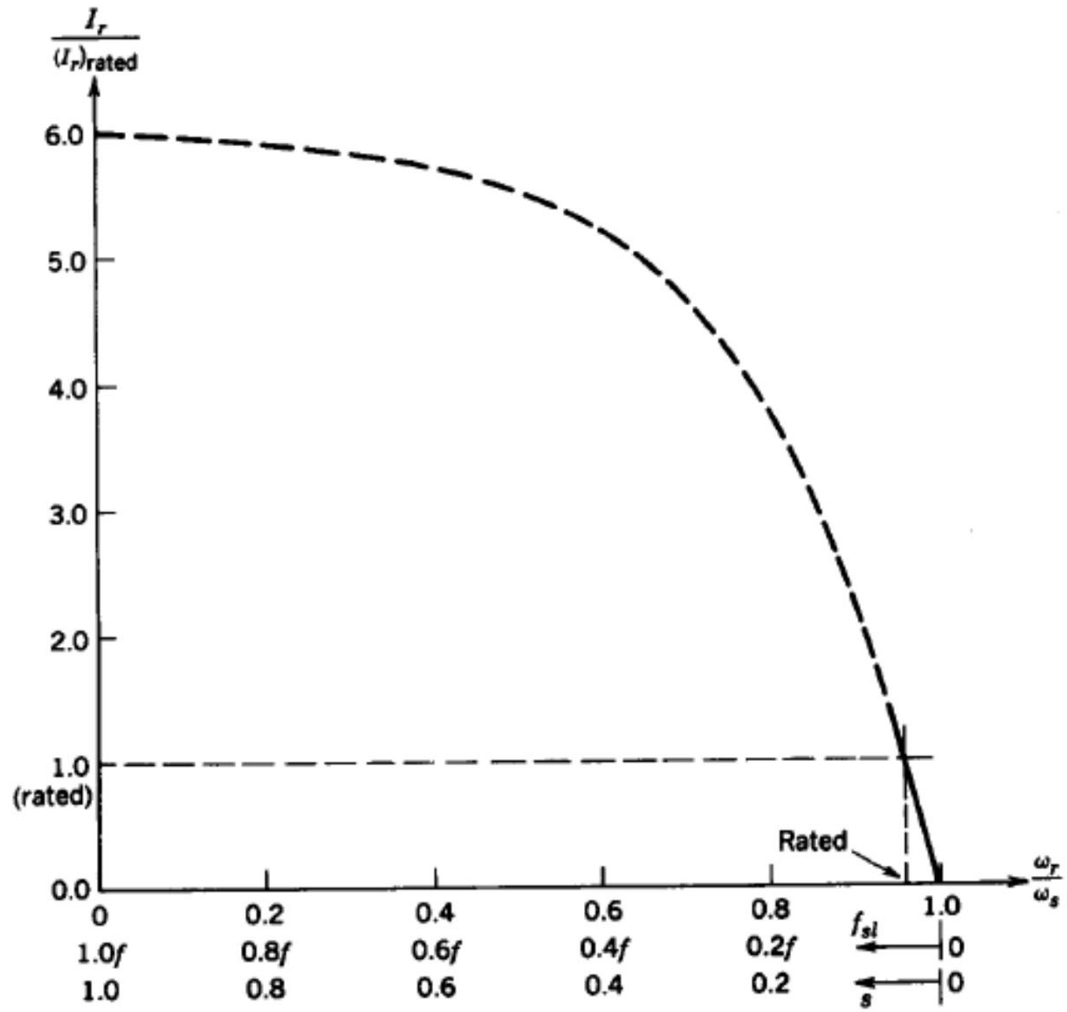
Induction motor

- Linear area used for speed control



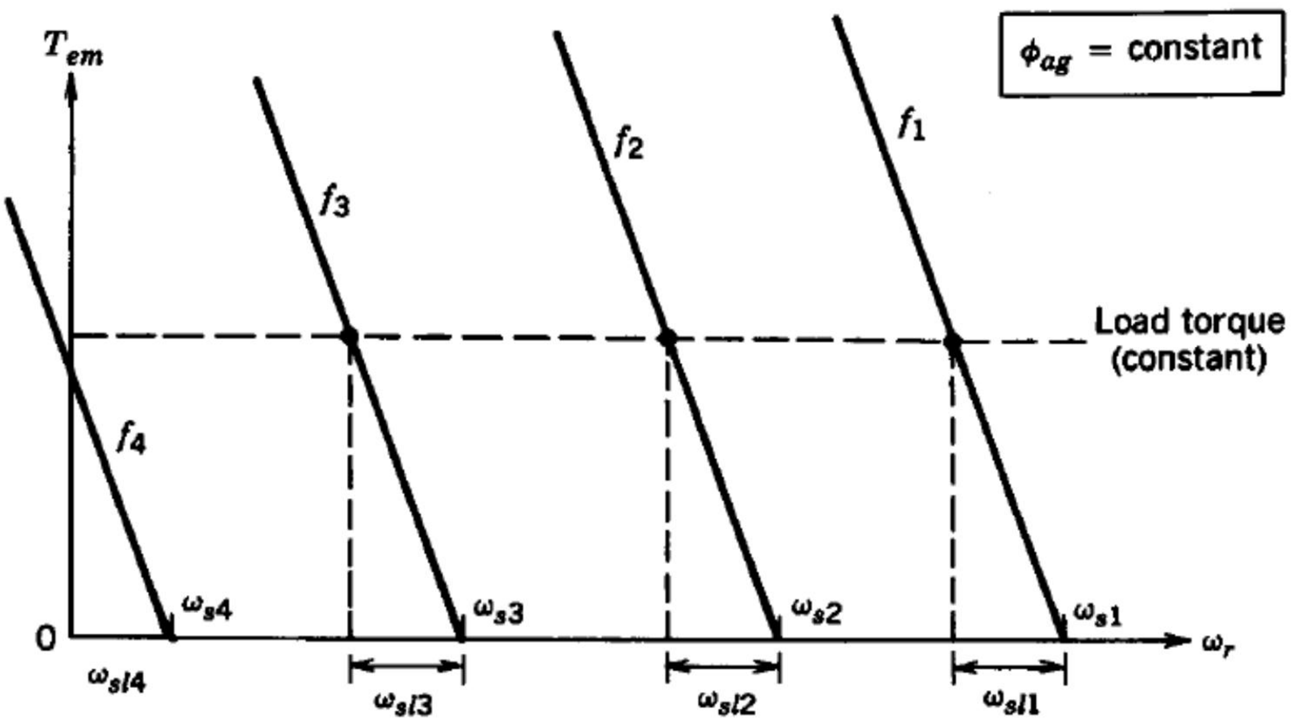
Induction motor current

- Fixed V_s and f
- Large start-up current if not controlled

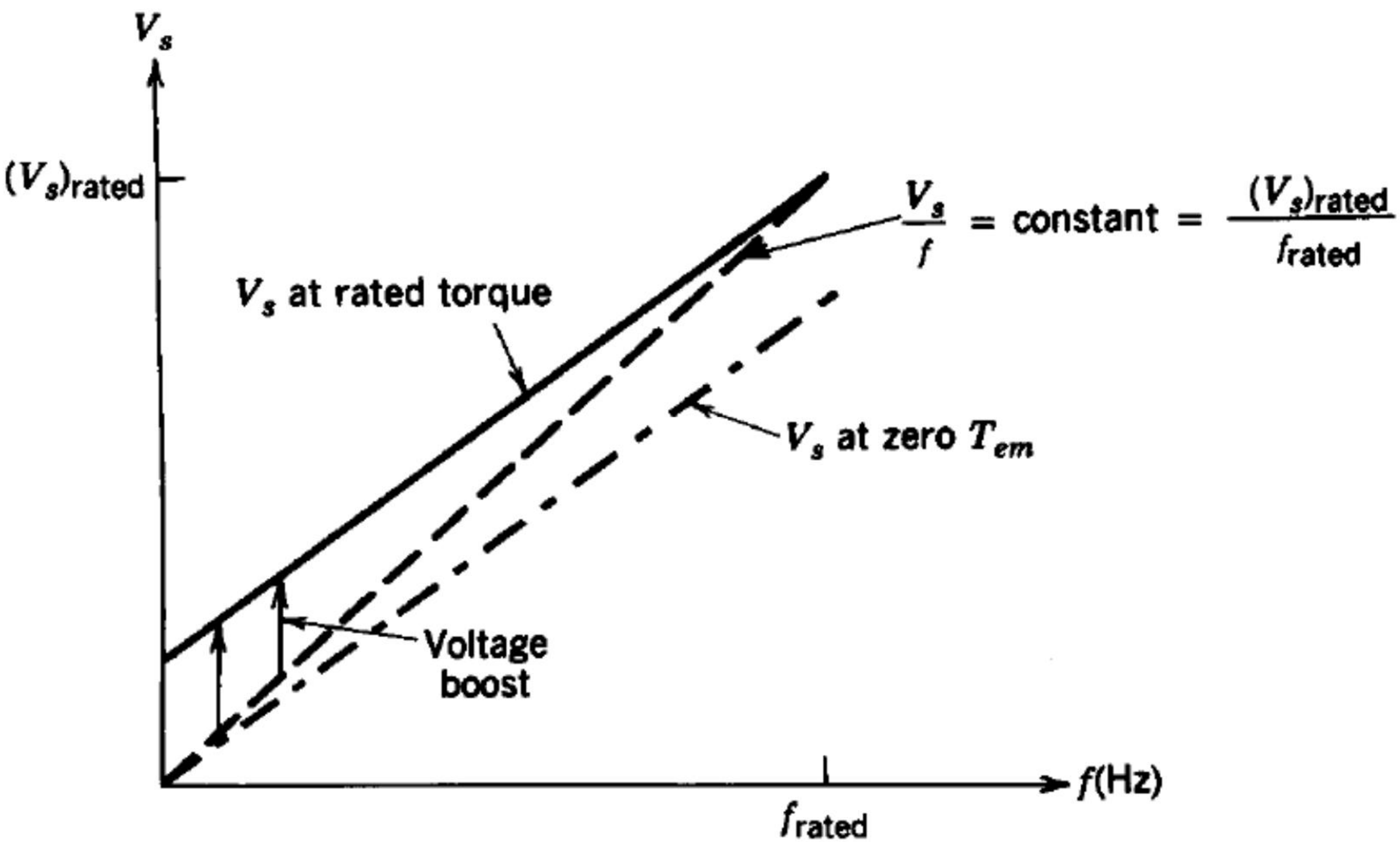


Induction motor speed control

- Air gap flux constant by changing V_s proportional to f

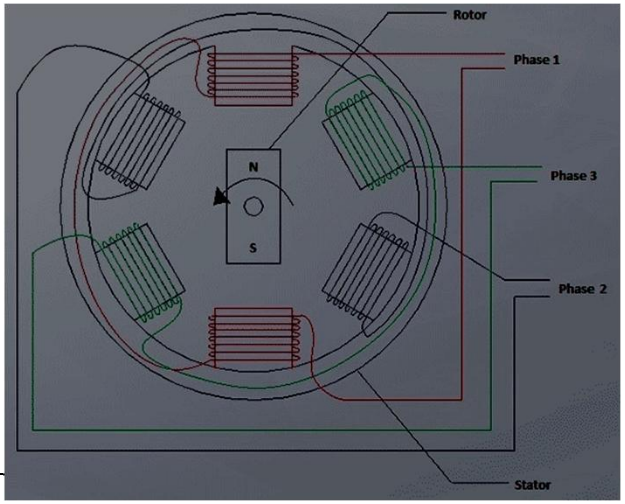


Constant air-gap flux: $\frac{V_s}{f} = constant$



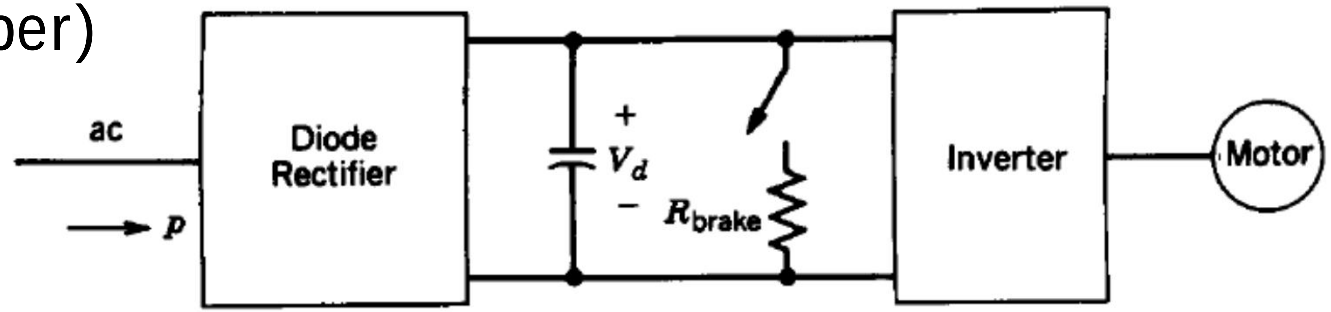
Synchronous motor drive

- Fixed rotor magnetization
  - Permanent magnet rotor winding (larger motors)
- Rotating magnetic field in the field winding
  - Motor speed defined by magnetic rotation speed
- Also known as “brushless dc” motor

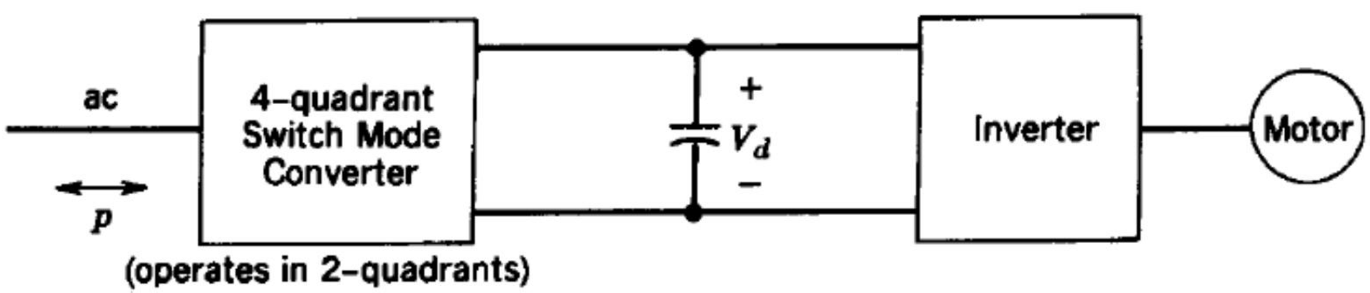


Converter system for motor drive

- PWM-VSI (Voltage Source Inverter)
  a) Diode rectifier – Dissipative braking (chopper)



  b) 4-quadrant switch mode rectifier – Regenerative braking



Lecture 15

Harmonics

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Fourier series

$$f(t) = F_0 + \sum_{h=1}^{\infty} f_h(t) = \tfrac{1}{2}a_0 + \sum_{h=1}^{\infty} \{a_h\cos(h\omega t) + b_h\sin(h\omega t)\}$$

where $F_0 = \tfrac{1}{2}a_0$ is the average value

$$a_h = \frac{1}{\pi}\int_0^{2\pi} f(t)\cos(h\omega t)\, d(\omega t) \qquad h = 0, \cdot\cdot\cdot, \infty$$

$$b_h = \frac{1}{\pi}\int_0^{2\pi} f(t)\, \sin(h\omega t)\, d(\omega t) \qquad h = 1, \cdot\cdot\cdot, \infty$$

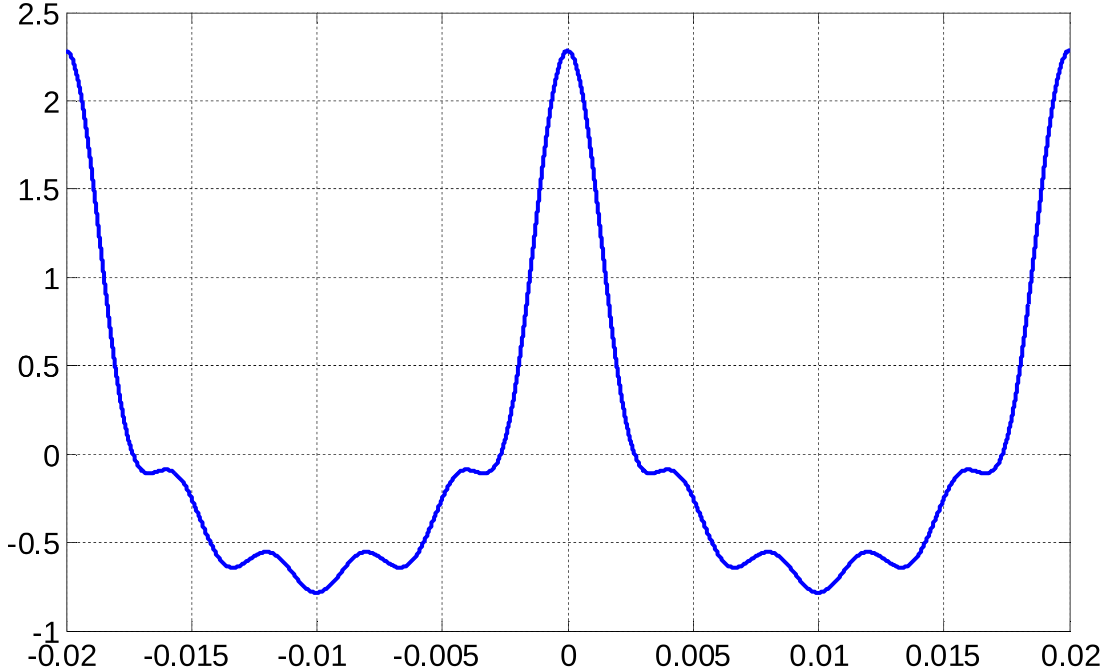
Fourier analysis

Table 3-1 Use of Symmetry in Fourier Analysis

Symmetry	*Condition Required*	a_h and b_h
Even	$f(-t) = f(t)$	$b_h = 0 \quad a_h = \frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\, d(\omega t)$
Odd	$f(-t) = -f(t)$	$a_h = 0 \quad b_h = \frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\, d(\omega t)$
Half-wave	$f(t) = -f(t + \frac{1}{2}T)$	$a_h = b_h = 0$ for even h $a_h = \frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\, d(\omega t)$ for odd h $b_h = \frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\, d(\omega t)$ for odd h
Even quarter-wave	Even and half-wave	$b_h = 0$ for all h $a_h = \begin{cases} \frac{4}{\pi}\int_0^{\pi/2} f(t)\cos(h\omega t)\, d(\omega t) & \text{for odd } h \\ 0 & \text{for even } h \end{cases}$
Odd quarter-wave	Odd and half-wave	$a_h = 0$ for all h $b_h = \begin{cases} \frac{4}{\pi}\int_0^{\pi/2} f(t)\sin(h\omega t)\, d(\omega t) & \text{for odd } h \\ 0 & \text{for even } h \end{cases}$

Even function $f(-t) = f(t)$

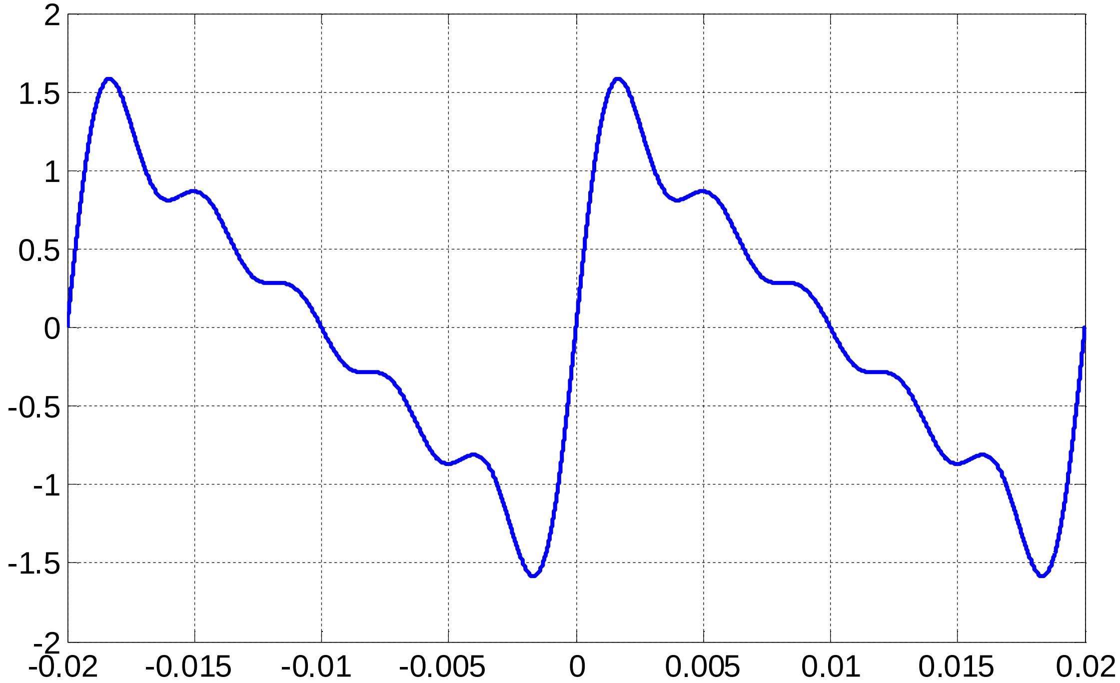
$$\cos(\omega t) + \frac{1}{2}\cos(2\omega t) + \frac{1}{3}\cos(3\omega t) + \frac{1}{4}\cos(4\omega t) + \frac{1}{5}\cos(5\omega t)$$



Odd function

$$f(-t) = -f(t)$$

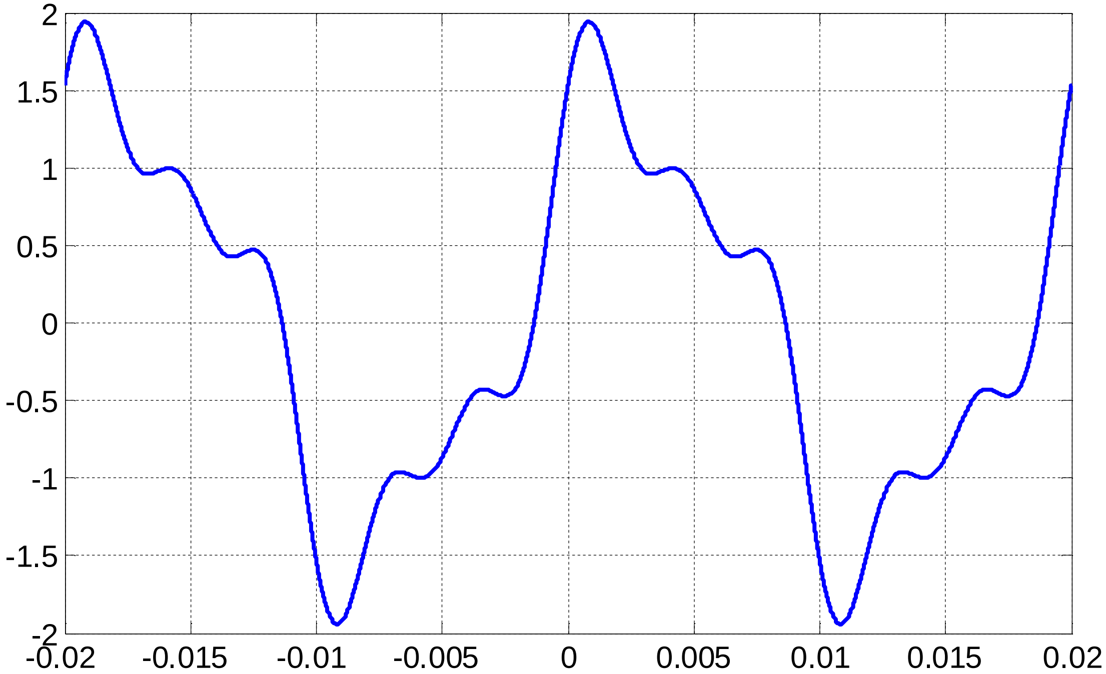
$$\sin(\omega t) + \frac{1}{2} sin(2\omega t) + \frac{1}{3}\sin(3\omega t) + \frac{1}{4}\sin(4\omega t) + \frac{1}{5}\sin(5\omega t)$$



Half-wave symmetry

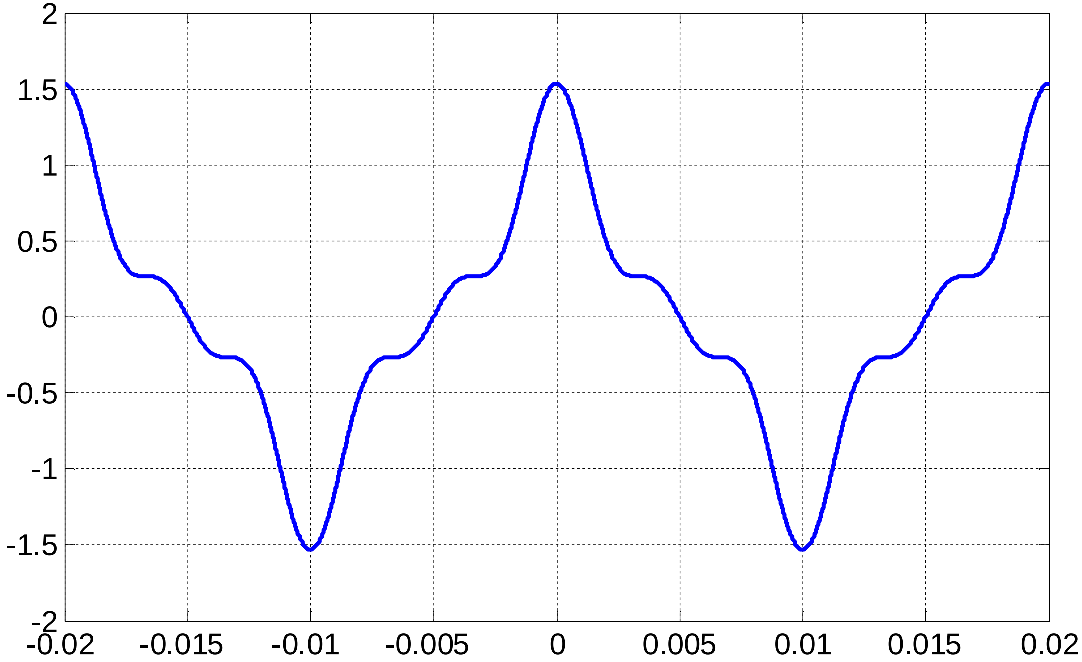
$$f(t) = -f(t + \tfrac{1}{2}T)$$

$$\sin(\omega t) + \cos(\omega t) + \frac{1}{3} sin(3\omega t) + \frac{1}{3}\cos(3\omega t) + \frac{1}{5}\sin(5\omega t) + \frac{1}{5}\cos(5\omega t)$$



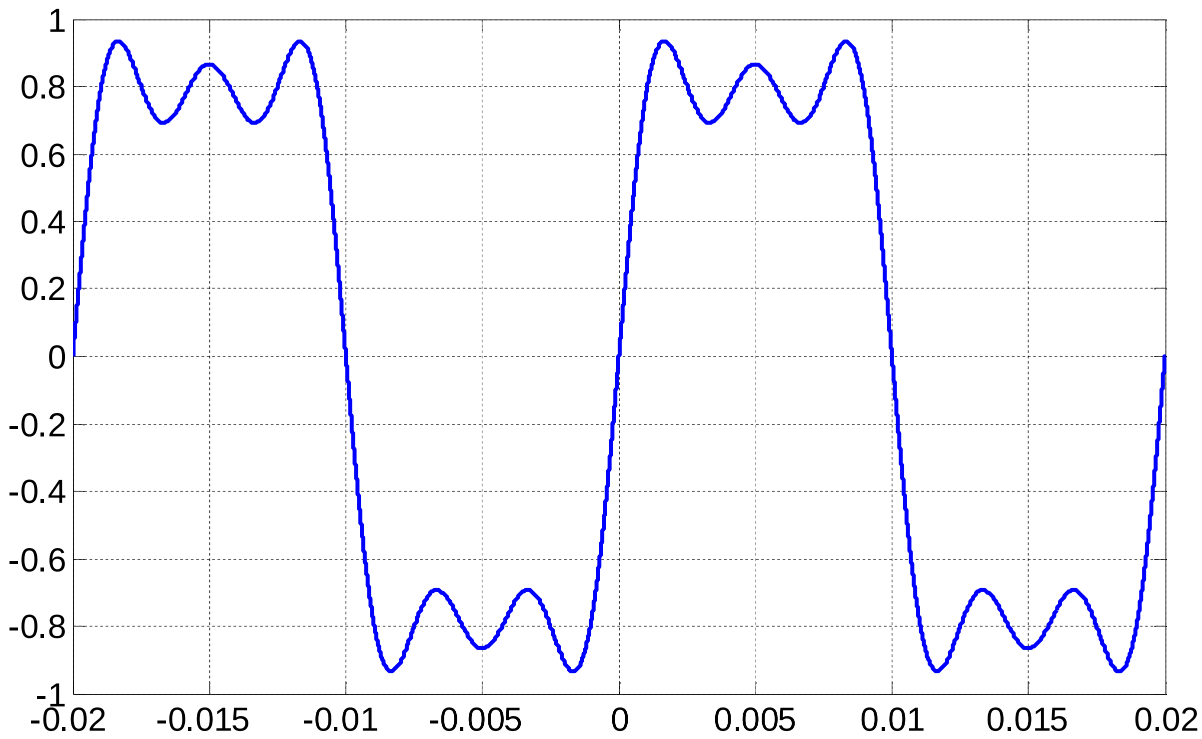
Even function, half-wave symmetry

$$\cos(\omega t) + \frac{1}{3}\cos(3\omega t) + \frac{1}{5}\cos(5\omega t)$$



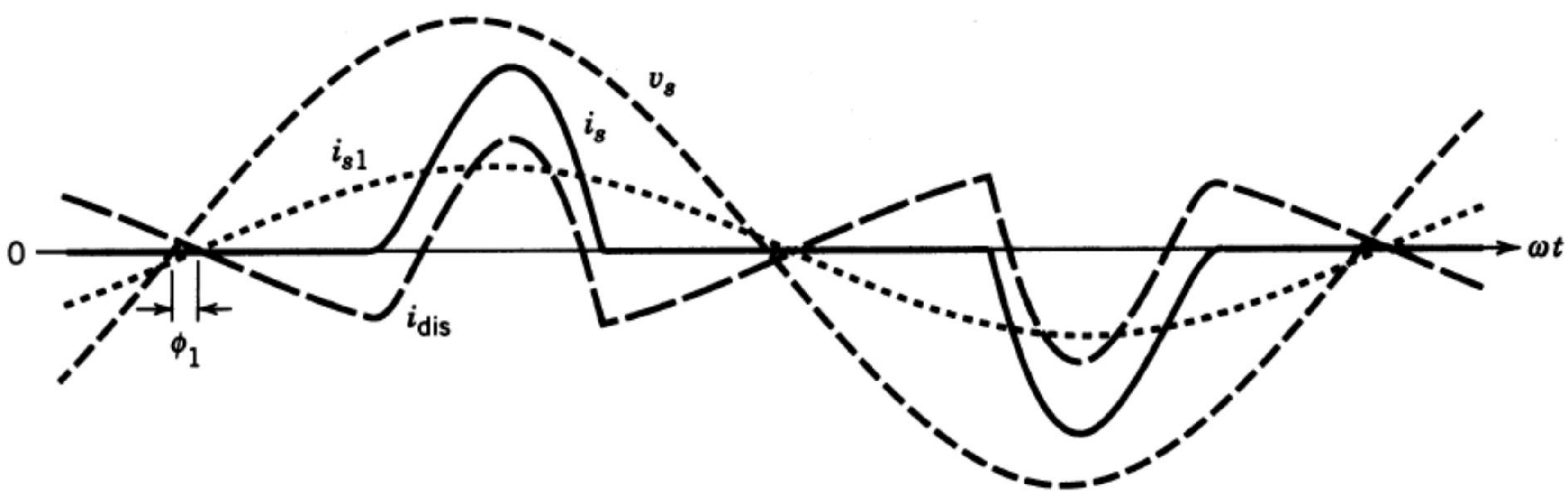
Odd function, half-wave symmetry

$$\sin(\omega t) + \frac{1}{3}\sin(3\omega t) + \frac{1}{5}\sin(5\omega t)$$



Total RMS incl harmonics

- $i_s(t) = i_{s1}(t) + \sum_{h=2}^{n} i_{sh}(t)$
- $I_s = \sqrt{\frac{1}{T_1}\int_0^{T_1} i_s^2(t)dt} = \sqrt{I_{s1}^2 + \sum_{h=2}^{n} I_{sh}^2} = \sqrt{I_{s1}^2 + I_{s3}^2 + I_{s5}^2 \ldots\ldots}$
- (All cross-product terms, $i_{s1} \cdot i_{s2}, i_{s1} \cdot i_{s3}$=0)



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