Midterm Exam **ENM060 Power Electronic Converters - Solutions**
Monday November 23, 2015

Lecturer: Andreas Henriksson, 0709-524924
Help: CTH approved calculator (Casio FX82, Texas TI30, Sharp EL531)
Solutions: Will be posted on the course webpage (2015-11-24).
Mark list: Handed out 2015-12-02 at 15:15 in ML11
Pick-up of Exam Handed out 2015-12-02 at 15:15 in ML11

Each question is connected to a lecture (1 to 8). The bonus points are rewarded as follows:
-2p: 0-4p
+1p: 5-14p
+2p: 15-19p
+3p: 20-25p

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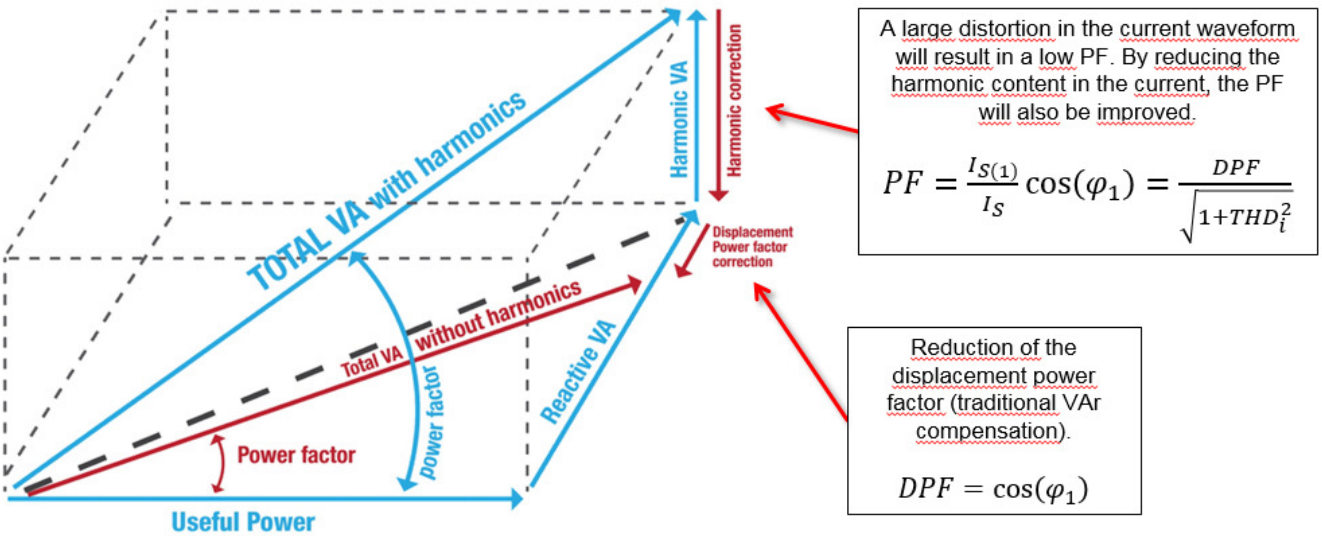
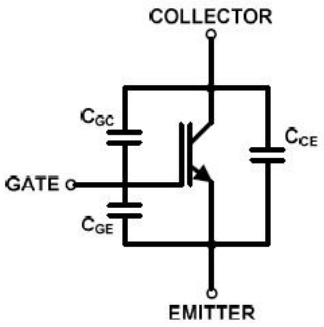
1. Explain the difference between power factor (PF) and displacement power factor (DPF). (4p)

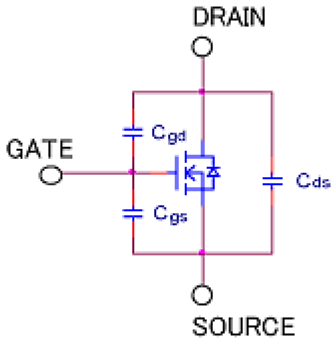
For non-sinusoidal quantities, DPF and PF will differ depending on the harmonic content.
DPF only takes the angle between the fundamental components into consideration
PF accounts for the angle between the fundamental components as well as the ratio between the fundamental current component and the total RMS-current (including harmonics)



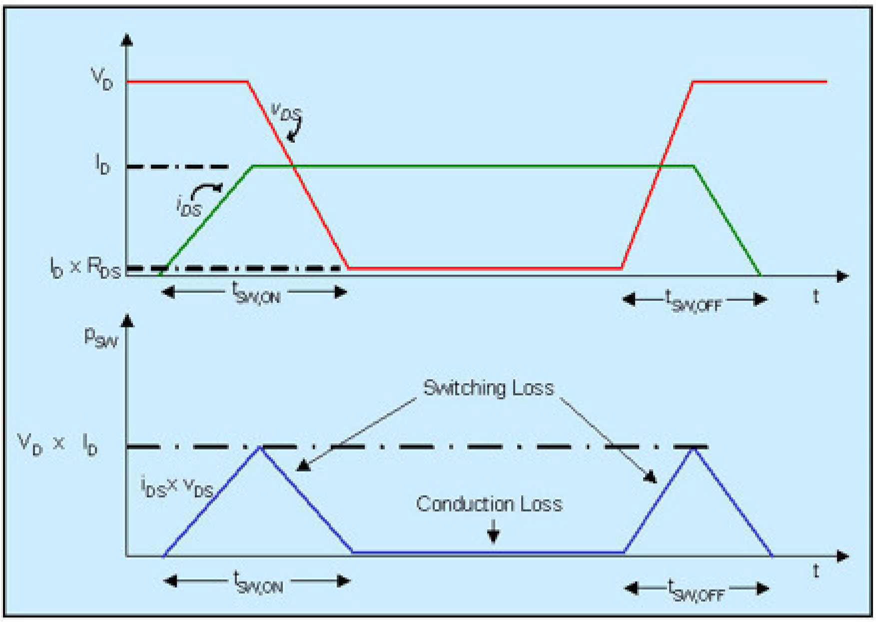
2. Compare the switching of and IGBT and an MOSFET. Exemplify with e.g. currents and/or voltages curve forms, drive circuits and component design. (3p)

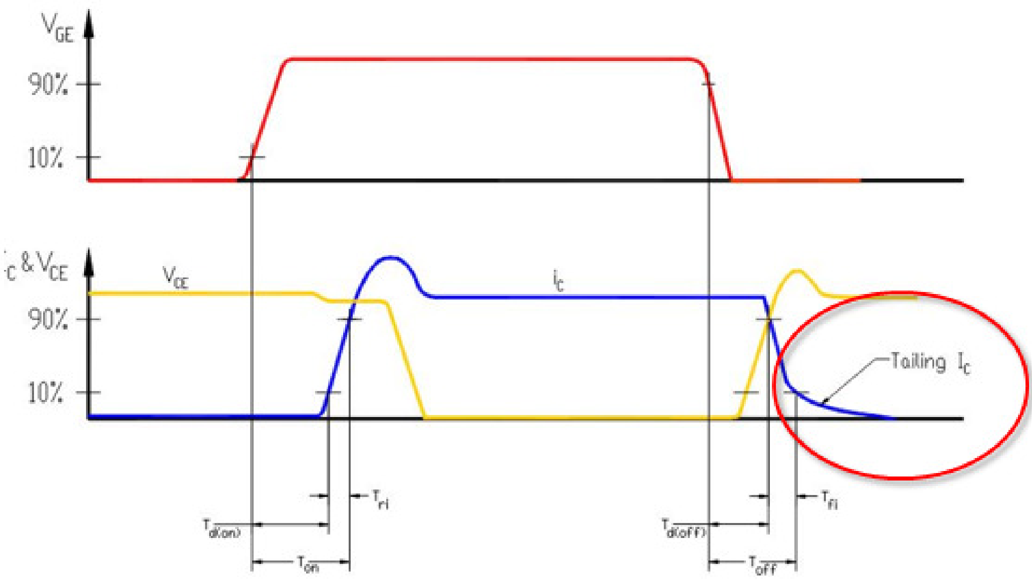
Both components have an insulated gate (MOS-interface) that makes the component voltage controlled. The internal capacitances ant the equivalent dynamic circuits are similar.



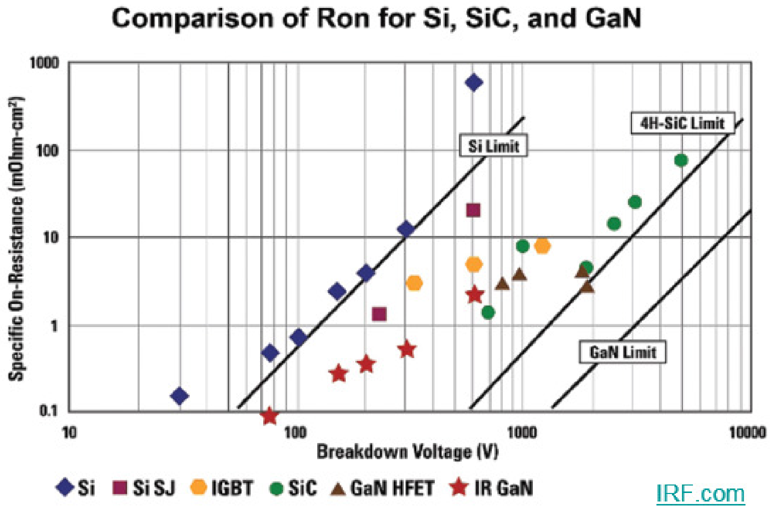


The largest difference in terms of switching lies within the fact that the IGBT is a minority carrier device in which the charges within the component has to swept out of the component at turn-off which results in a tailing current. The MOSFET does not exhibit this behaviour since it is a minority carrier device in which the current is mainly due to a flow of minority carriers.





3. **Name two upcoming technologies that can replace silicon (Si) as a semiconductor material in power electronic switches in the future. (2p)**



The two most promising alternatives today are Silicon Carbide (SiC) Gallium Nitride (GaN).

4. **Draw an equivalent circuit model for a capacitor and explain what each circuit element represents. (3p)**

- Equivalent series resistance (ESR)

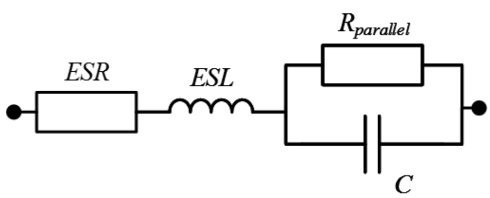
  The sum of all ohmic losses and dielectric losses within the capacitor
  Complex to determine, depends on material, temperature and frequency

- Leakage current and insulation resistance

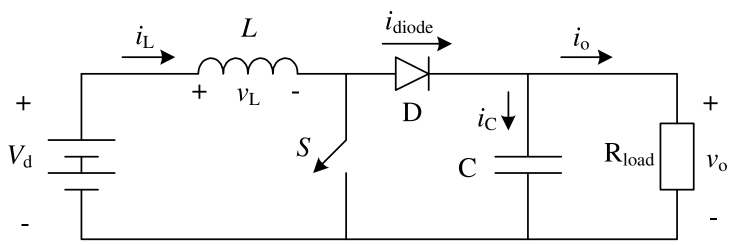
  A small DC-current will flow through the dielectric due to non-idealities.
  Temperature and material dependent

- Equivalent Series Inductance (ESL)

  Depends on the package
  Typically 1-100nH



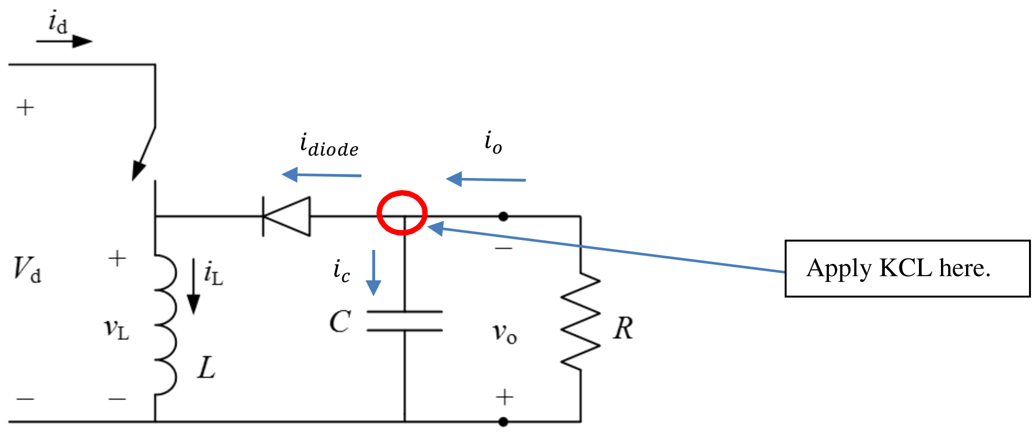
5. **For a boost converter, derive an expression of the ratio between the input and output voltage when it is operating in continuous conduction mode (CCM). (3p)**

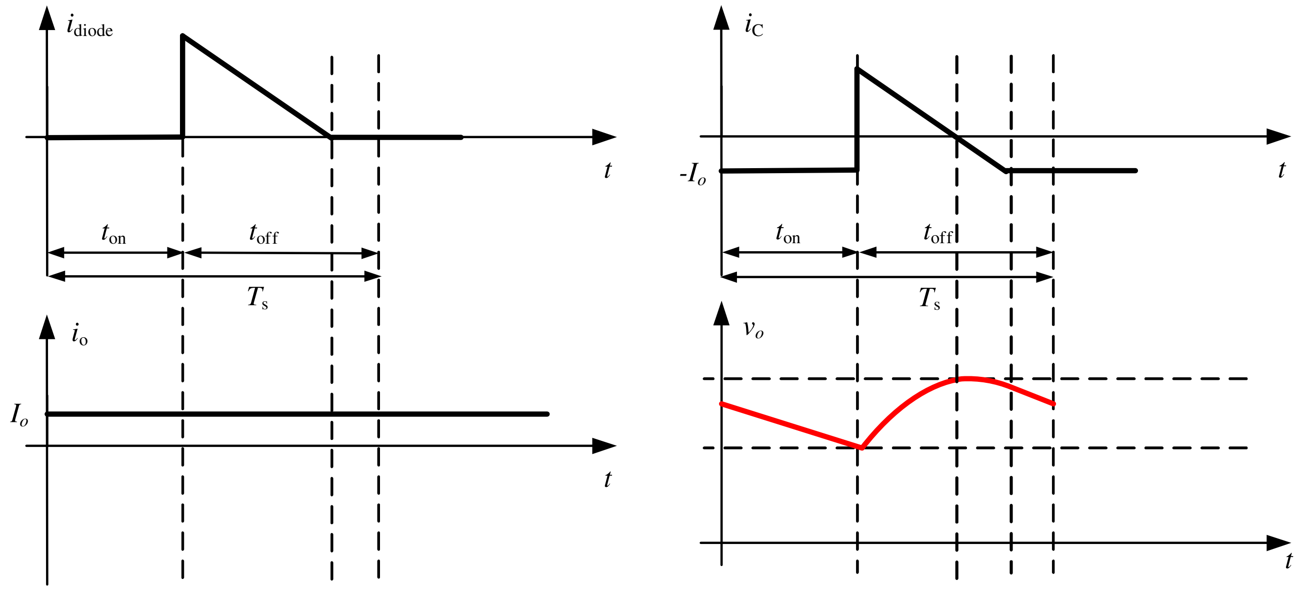


$$V_L = \frac{1}{T_{sw}} \int_0^{T_{sw}} v_L dt = \frac{1}{T_{sw}} (V_d D T_{sw} + (V_d - V_o)(1-D)T_{sw}) = V_d + V_o(1-D) = 0$$

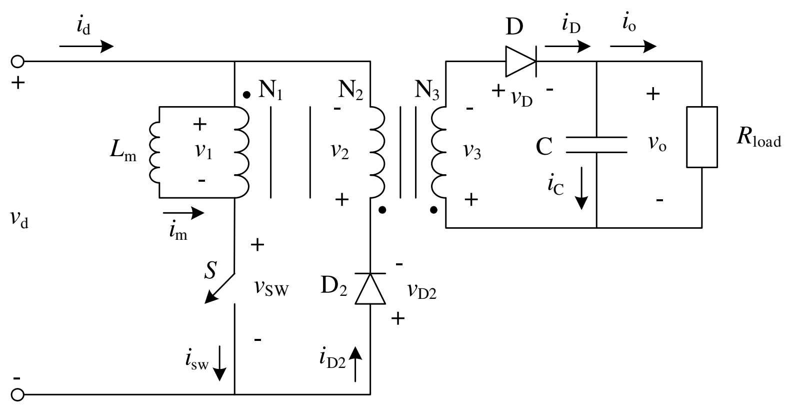
$$V_o = \frac{V_d}{1-D} \quad \rightarrow \quad D = \frac{V_o - V_d}{V_o}$$

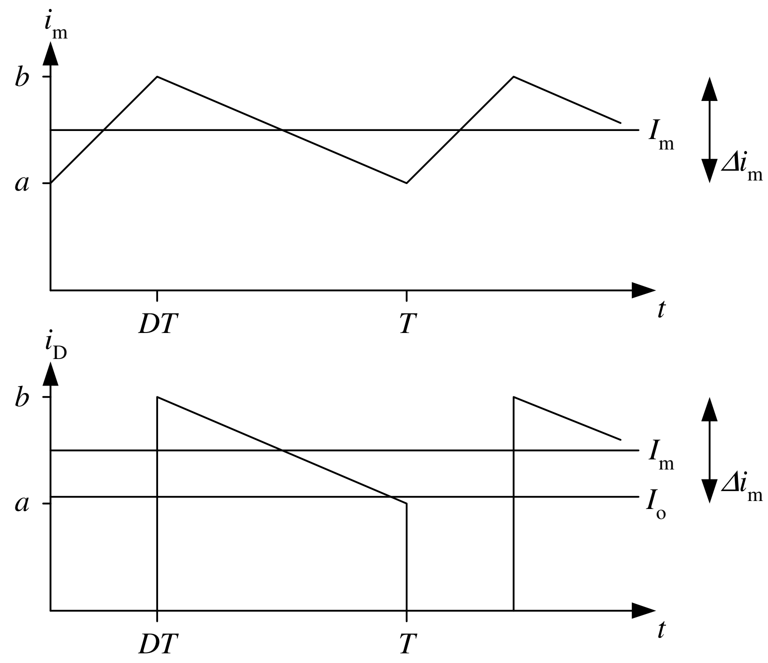
6. **For the buck/boost converter below, apply Kirchhoff's current law on the node below and draw the three current flowing in/out of the node when it is operating in DCM. Also, draw the resulting voltage ripple. (4p)**





7. **The flyback converter below has a protective winding (N_2) and the total turns ratio of the transformer $(N_1{:}N_2{:}N_3)$ is $(1{:}1{:}1)$. If the converter is operating in CCM, derive an expression of how the average magnetizing current (I_m) relates to the average output current (I_o). (3p)**





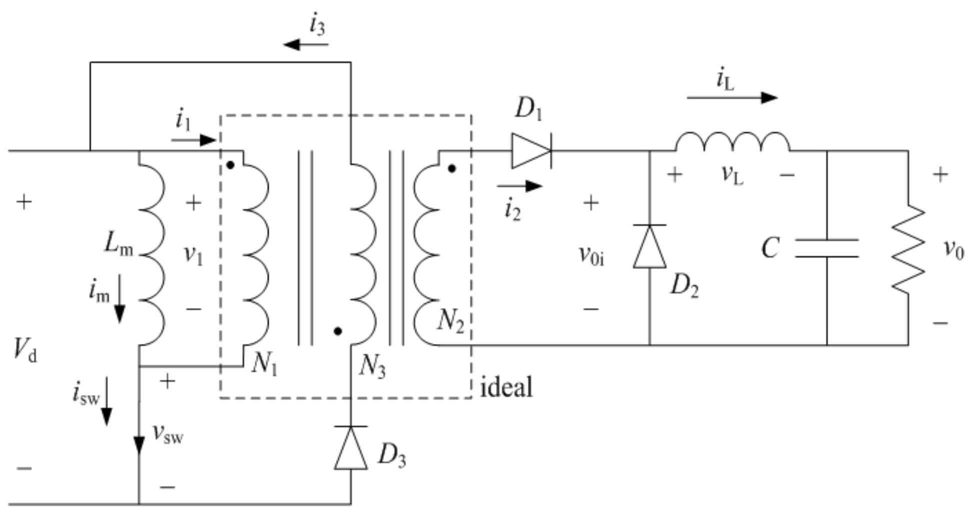
From the figure we see that the average magnetizing current can be calculated as:

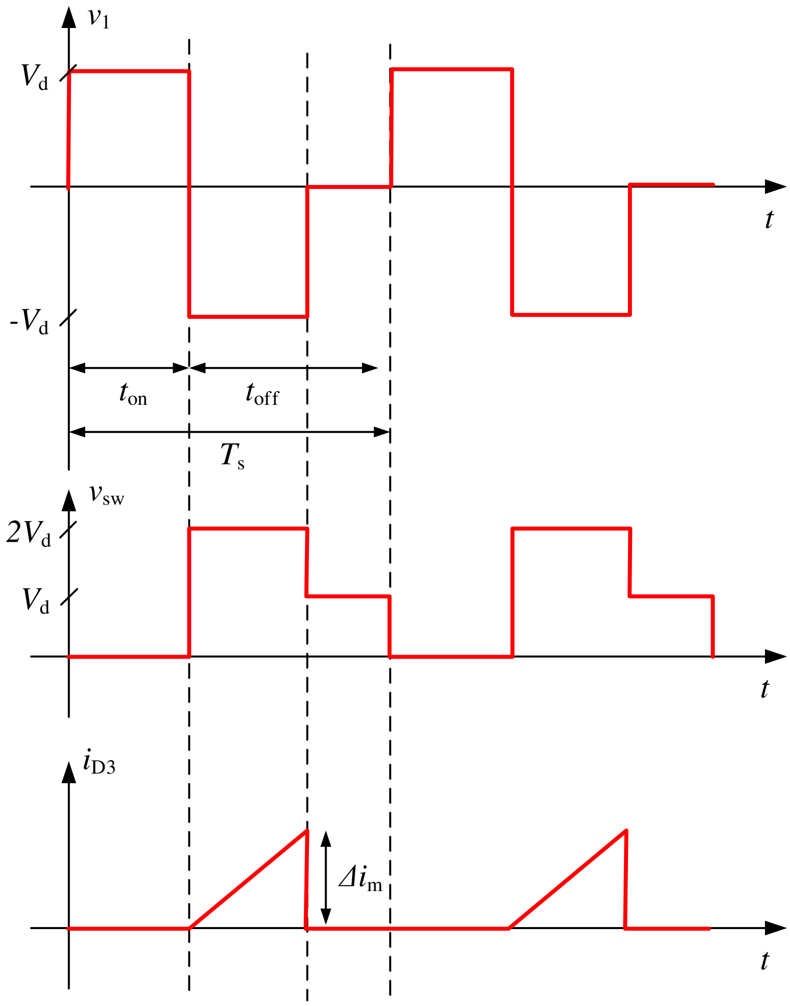
$$I_m = \frac{1}{T_{sw}}\int_0^{T_{sw}} i_m(t)dt = \frac{1}{T_{sw}}\int_0^{DT_{sw}} i_m(t)dt + \frac{1}{T_{sw}}\int_{DT_{sw}}^{T_{sw}} i_m(t)dt = \frac{a+b}{2T}DT + \frac{a+b}{2T}(1-D)T = \frac{a+b}{2}$$

$$I_o = \frac{1}{T_{sw}}\int_0^{T_{sw}} i_D(t)dt = \frac{1}{T_{sw}}\int_{DT_{sw}}^{T_{sw}} i_m(t)dt = \frac{a+b}{2T}(1-D)T = \frac{a+b}{2}(1-D) = I_m(1-D)$$

This is a simple relation between the average output current and the average magnetizing current.

8. Assume that the forward converter below is operating in CCM with D=0.3 and that all windings on the transformer have the same number of turns ($N_1 : N_2 : N_3 = 1 : 1 : 1$). Draw the resulting voltage over the switch (v_{sw}) and the current that flows through diode D_3. (3p)





v_1
V_d
$-V_d$
t
t_{on}
t_{off}
T_s
v_{sw}
$2V_d$
V_d
t
i_{D3}
Δi_m
t

Formulas for Examination in Power Electronic Converters (ENM060)

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 $b_h = \begin{cases} \frac{4}{\pi}\int_0^{\pi/2} f(t)\sin(h\omega t)\, d(\omega t) & \text{for odd } h \\ 0 & \text{for even } h \end{cases}$

Definition of RMS-value:

$$F_{RMS} = \sqrt{\frac{1}{T}\int_{t_o}^{t_o+T} f(t)^2 dt}$$

Definition of RMS-value with Fourier-series:

$$F_{RMS} = \sqrt{F_0^2 + \sum_{n=1}^{\infty} F_n^2} = \sqrt{\left(\frac{a_0}{2}\right)^2 + \sum_{n=1}^{\infty}\left(\frac{\sqrt{a_n^2 + b_n^2}}{\sqrt{2}}\right)^2}$$

$$\sin^2(\alpha) + \cos^2(\alpha) = 1$$

$$\sin(\alpha+\beta) = \sin(\alpha)\cos(\beta) + \cos(\alpha)\sin(\beta) \qquad \sin(\alpha-\beta) = \sin(\alpha)\cos(\beta) - \cos(\alpha)\sin(\beta)$$

$$\cos(\alpha+\beta) = \cos(\alpha)\cos(\beta) - \sin(\alpha)\sin(\beta) \qquad \cos(\alpha-\beta) = \cos(\alpha)\cos(\beta) + \sin(\alpha)\sin(\beta)$$

$$\sin(\alpha)\sin(\beta) = \frac{1}{2}\left(\cos(\alpha-\beta) - \cos(\alpha+\beta)\right) \qquad \sin(\alpha)\cos(\beta) = \frac{1}{2}\left(\sin(\alpha-\beta) + \sin(\alpha+\beta)\right)$$

$$\cos(\alpha)\cos(\beta) = \frac{1}{2}\left(\cos(\alpha-\beta) + \cos(\alpha+\beta)\right)$$

$$\int \sin(ax)dx = -\frac{1}{a}\cos(ax), \quad \int x\sin(ax)dx = \frac{1}{a^2}\left(\sin(ax) - ax\cos(ax)\right), \quad \int \cos(ax)dx = \frac{1}{a}\sin(ax)$$

$$\int x\cos(ax)dx = \frac{1}{a^2}\left(\cos(ax) + ax\sin(ax)\right)$$

$$PF = \frac{P}{S} = \frac{V_s I_{s1}\cos\phi_1}{V_s I_s}, \quad DPF = \cos\phi_1, \quad \%THD_i = 100\frac{I_{dis}}{I_{s1}} = 100\frac{\sqrt{I_s^2 - I_{s1}^2}}{I_{s1}} = 100\sqrt{\sum_{h\neq 1}\left(\frac{I_{sh}}{I_{s1}}\right)^2}$$

Electromagnetics

$$e = \frac{d}{dt}\psi \qquad \psi = N\phi \qquad \phi = BA \qquad R = \frac{l}{A\mu_r\mu_0} \qquad L = \frac{\Psi}{i}$$

$$NI = R\phi = mmf \qquad N\phi = LI \qquad L = A_L N^2 \qquad W = \frac{1}{2}LI^2$$

Simpson's rule

Let $f(x)$ be a polynomial of maximum third degree, this means

$$f(x) = a_1 + a_2 x + a_3 x^2 + a_4 x^3$$

For this function the integral can be calculated as

$$\frac{1}{T}\int_{t_0}^{t_0+T} f(x)dx = \frac{1}{6}\left(f(t_0) + 4f(t_0 + \frac{T}{2}) + f(t_0 + T)\right)$$