Institute of Energy Technology
Department of Electrical Energy Conversion

Power converters AC/DC and DC/AC - MM5

Filters etc.

Content MM6

1. Summary from MM5
2. Thermal design
3. Line disturbance
4. Filters (AC & DC)
5. Standard & Norms
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2. Thermal design

Temperature is important for

- Life time
- reliability
- Robustness
- Size of the apparatus
- Safeness
- Losses and efficiency

Rules of thumb

- Max. 150°C (Worst case)
- Failure rate doubles at 10°C increase in temperature
- Forced cooling reduces the size ⇒ Acoustic noise
  ⇒ Expensive, life time
  ⇒ system efficiency
- Water cooling for large amount of losses
- Black in better than polished
- The heat sink have to stand-up
- Ambient temperature typically 40 -50°C

2. Thermal design

Power electronic components

- Large current - small voltage
- Large voltage - small currents

⇓

Losses there have to be removed

$$P_{tot} \approx P_{on} + P_{off} + P_{switch} + P_{gate}$$

Notes :

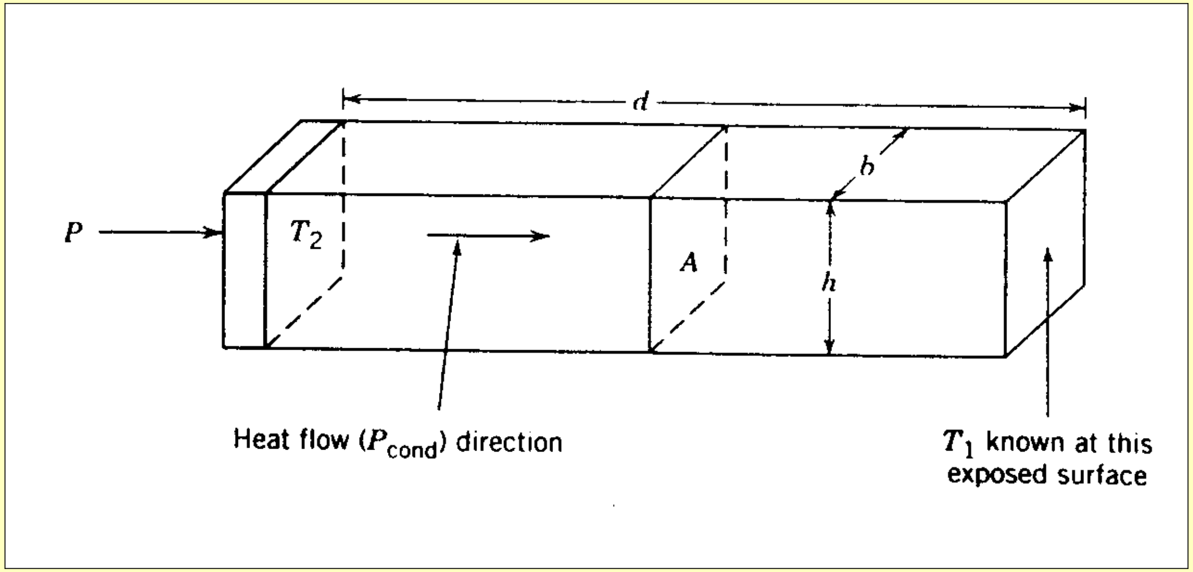
- Junction temperature (silicon 150°C)
- Ambient temperature (specified)
- Short circuit characteristics
- Reliability

How to do it :

- Heat-sink
- forced cooling (air over)

2. Thermal design

Thermal resistance



The conducted power

$$P_{cond} = \frac{\lambda A \, \Delta T}{d}$$

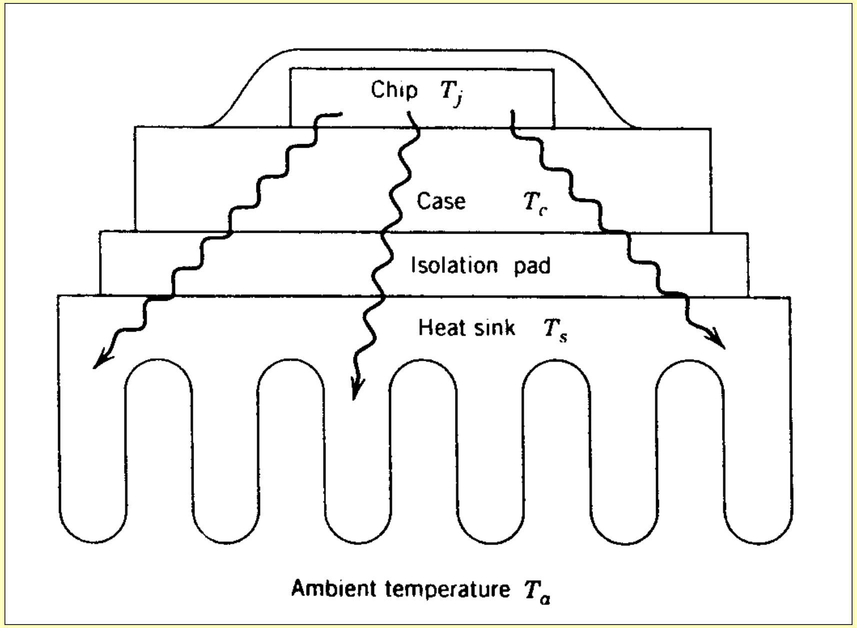
Thermal equivalent resistance

$$R_{\theta,cond} = \frac{\Delta T}{P_{cond}}$$

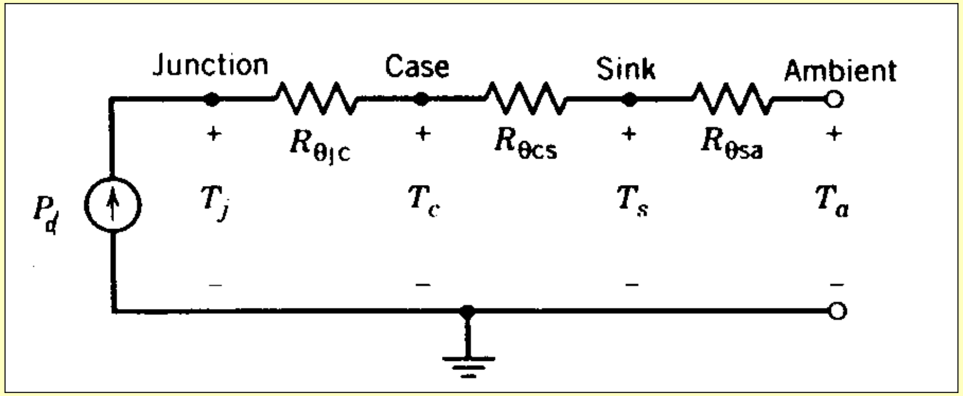
λ = Thermal conductivity [$Wm^{-1}°C^{-1}$]

2. Thermal design

Temperature (stationary)



Equivalent model



Total thermal equivalent resistance

$$R_{\theta ja} = R_{\theta jc} + R_{\theta cs} + R_{\theta sa}$$

Temperature

$$T_j = P_d(R_{\theta jc} + R_{\theta cs} + R_{\theta sa}) + T_a$$

40 - 60°C

2. Thermal design

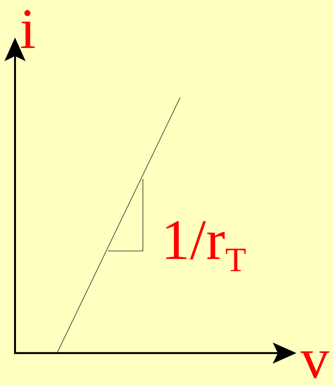
Thyristor

- Off-losses (~0)
- Turn-off losses (~0, 50/60 Hz)
- Gate losses (~0, 50/60 Hz)
- On-losses

"On" Power losses

$$P_T = \frac{1}{T}\int_0^T i_T \, v_T \, dt$$

$$v_T = r_T \, i_T + V_{T,0}$$



$$p_T = \frac{1}{T}\int_0^T i_T \, (r_T \, i_T + V_{T,0}) \, dt$$

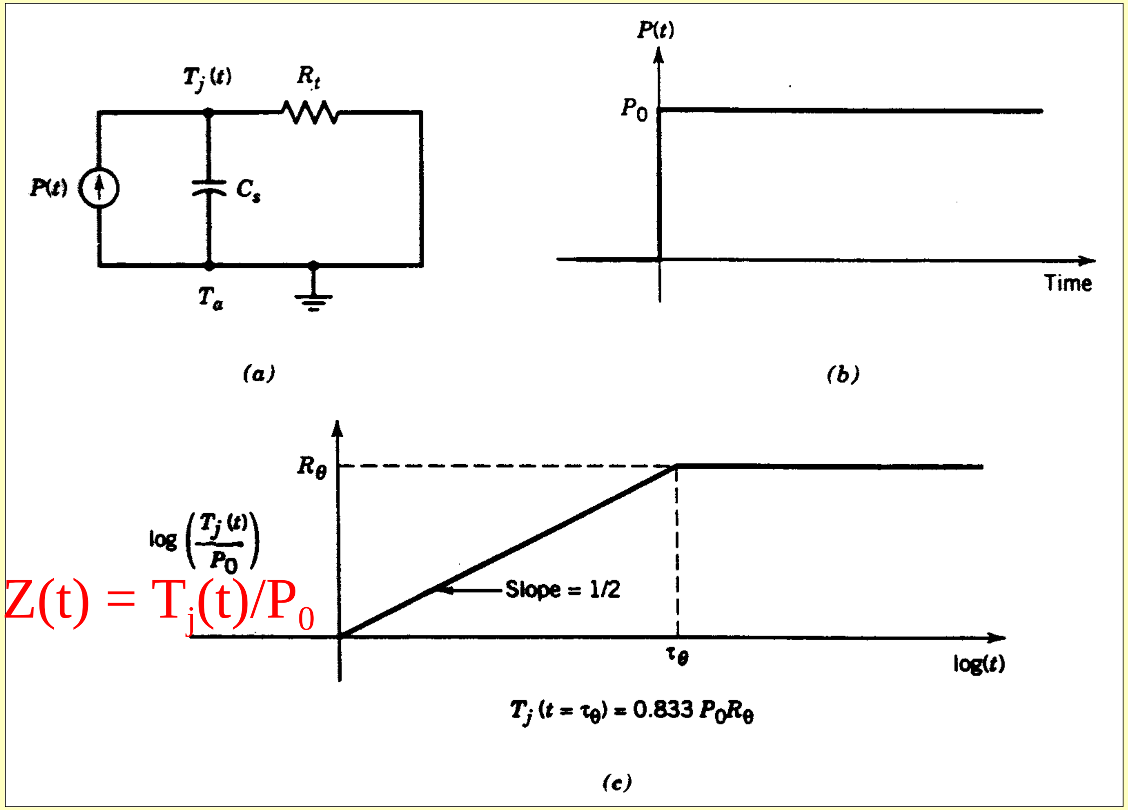
$$= r_T \frac{1}{T}\int_0^T i_T^2 \, dt + V_{T,0}\frac{1}{T}\int_0^T i \, dt$$

$$= r_T \, I_{T,RMS}^2 + V_{T,0} \, I_{T,av}$$

So we need RMS and average values

2. Thermal design

Simple transient model



$Z(t) = T_j(t)/P_0$

Capacity

$$dQ/dT = C_v$$

$$C_s = C_v A d$$

Capacity per unit volume

Temperature

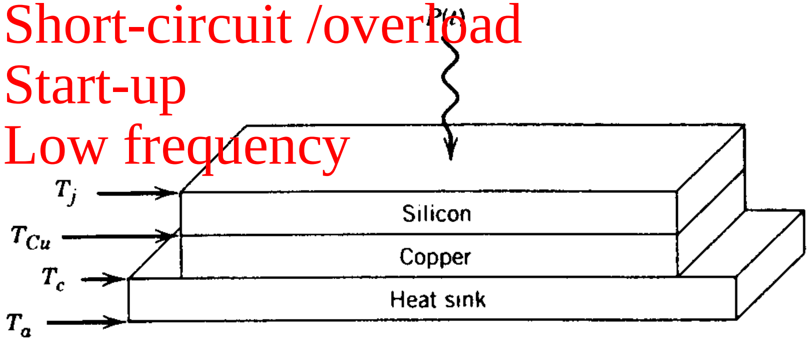
$$T_j(t) = P_0\,[4t/(\pi R_\theta C_s)]^{1/2} + T_a$$

$$\tau_\vartheta = \pi R_\theta C_s/4$$

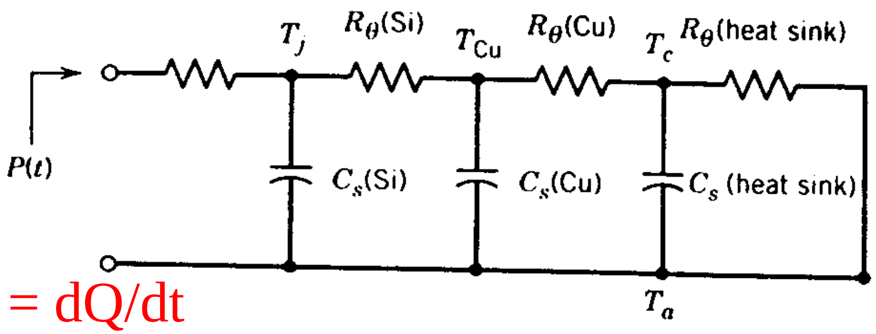
2. Thermal design

Transient thermal model

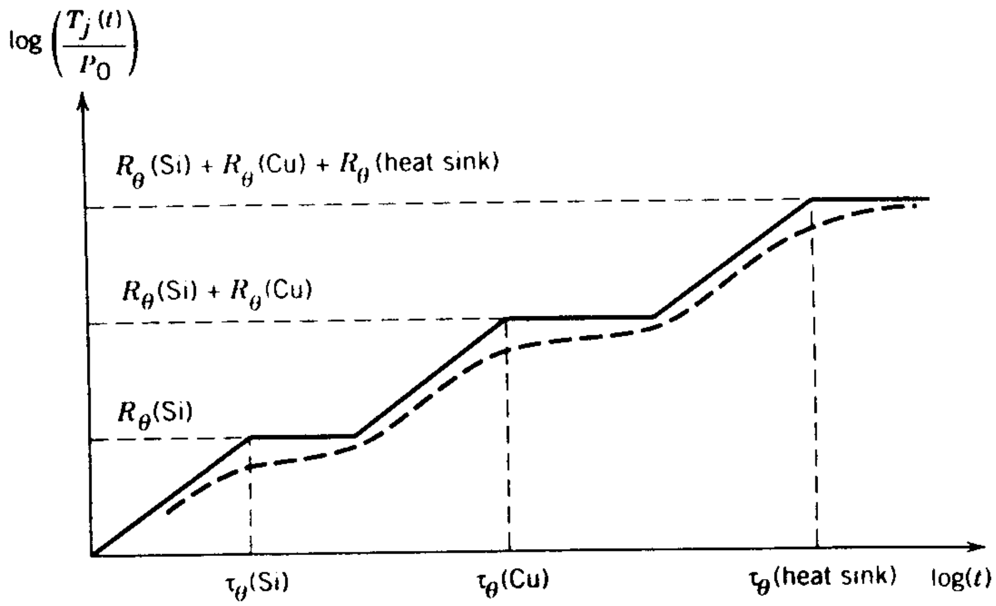
- Short-circuit /overload
- Start-up
- Low frequency

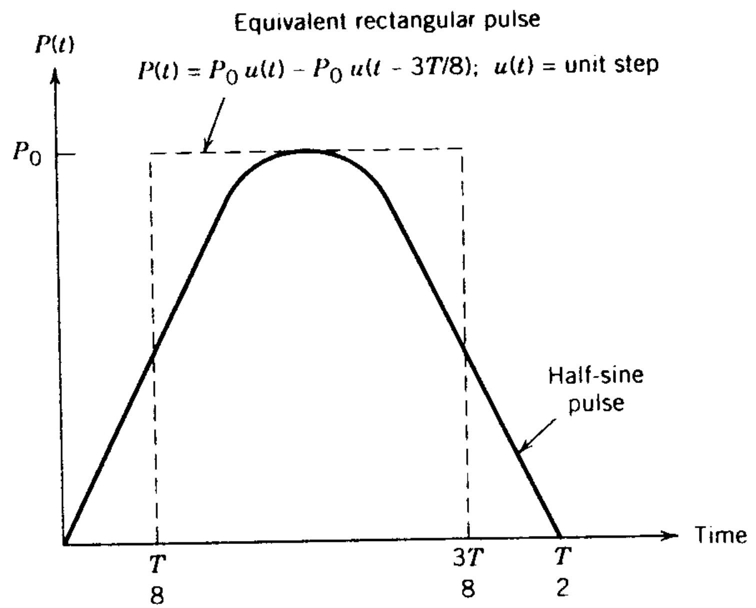


Equivalent circuit



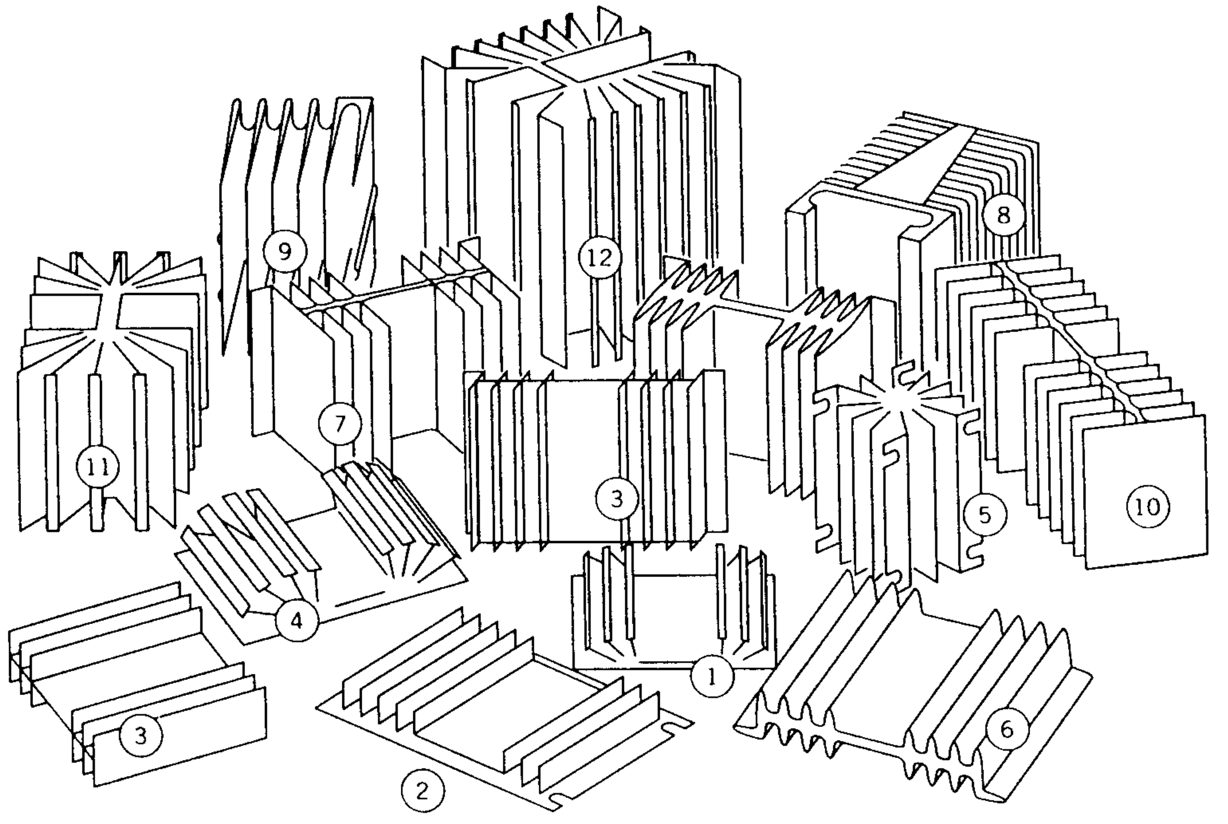
C = dQ/dt





2. Thermal design

Practical heat sinks



Heat sink no.	1	2	3	4	5	6	7	8	9	10	11	12
$R_{\theta sa}$ (°C/W)	3.2	2.3	2.2	0	2.1	1.7	1.3	1.3	1.25	1.2	0.8	0.65
Vol. (cm^3)	76	99	181	0	198	298	435	675	608	634	695	1311

Many different in lab.

2. Thermal design

Heat transfer by radiation and convection

Radiation

A = surface area

$$P_{rad} = 5.7 \times 10^{-8} EA(T_s^4 - T_a^4)$$

Black oxidized aluminum : E = 0.9
Polished aluminum : E = 0.05

Black oxidized aluminum

$$P_{rad} = 5.1A\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4\right]$$

Equivalent thermal resistance

$$R_{\theta,rad} = \frac{\Delta T}{5.1A\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4\right]}$$

Convection (heat-sink → air)

$$P_{conv} = 1.34A \frac{(\Delta T)^{1.25}}{(d_{vert})^{0.25}}$$

d_{vert} = vertical height

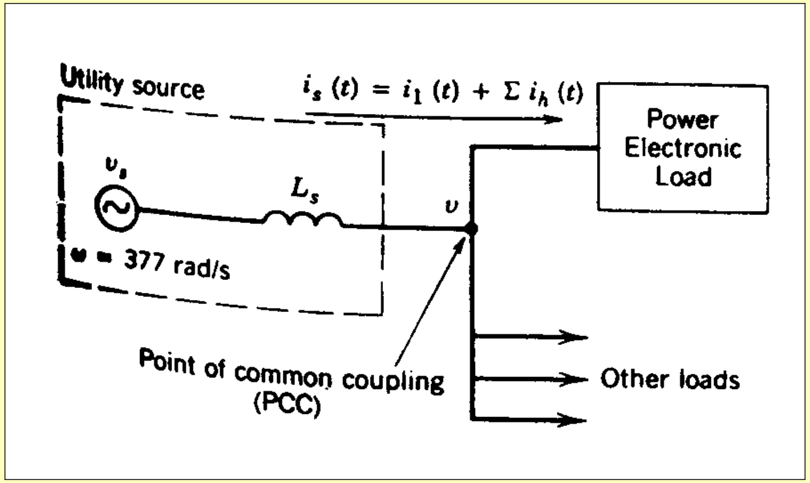
Equivalent thermal resistance

$$R_{\theta,conv} = \frac{1}{1.34A}\left(\frac{d_{vert}}{\Delta T}\right)^{1/4}$$

Total resistance is a parallel connection of $R_{\theta,rad}$ and $R_{\theta,conv}$

3. Line disturbance

Loading the line

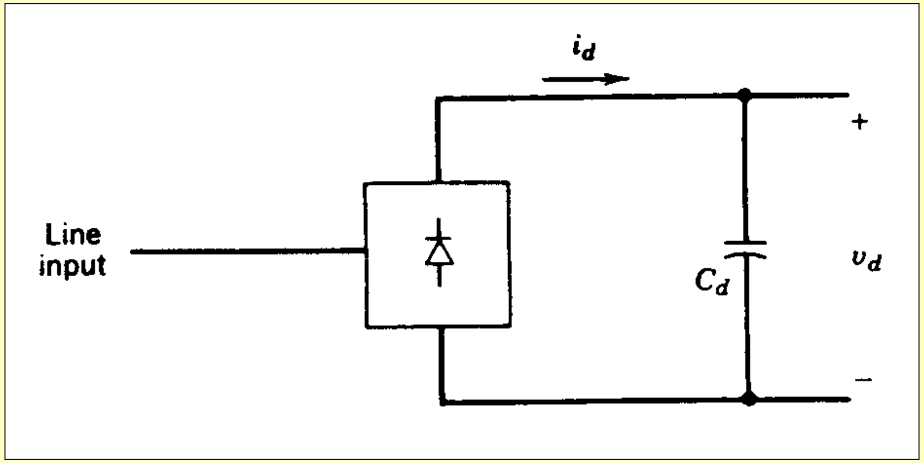


- Line conducted noise
- Airborne noise
- Noise in
- Noise out

L_s means a lot !!!

3. Line disturbance

Current harmonics



Typical values

h	3	5	7	9	11	13	15	17
$\left(\frac{I_h}{I_1}\right)\%$	73.2	36.6	8.1	5.7	4.1	2.9	0.8	0.4

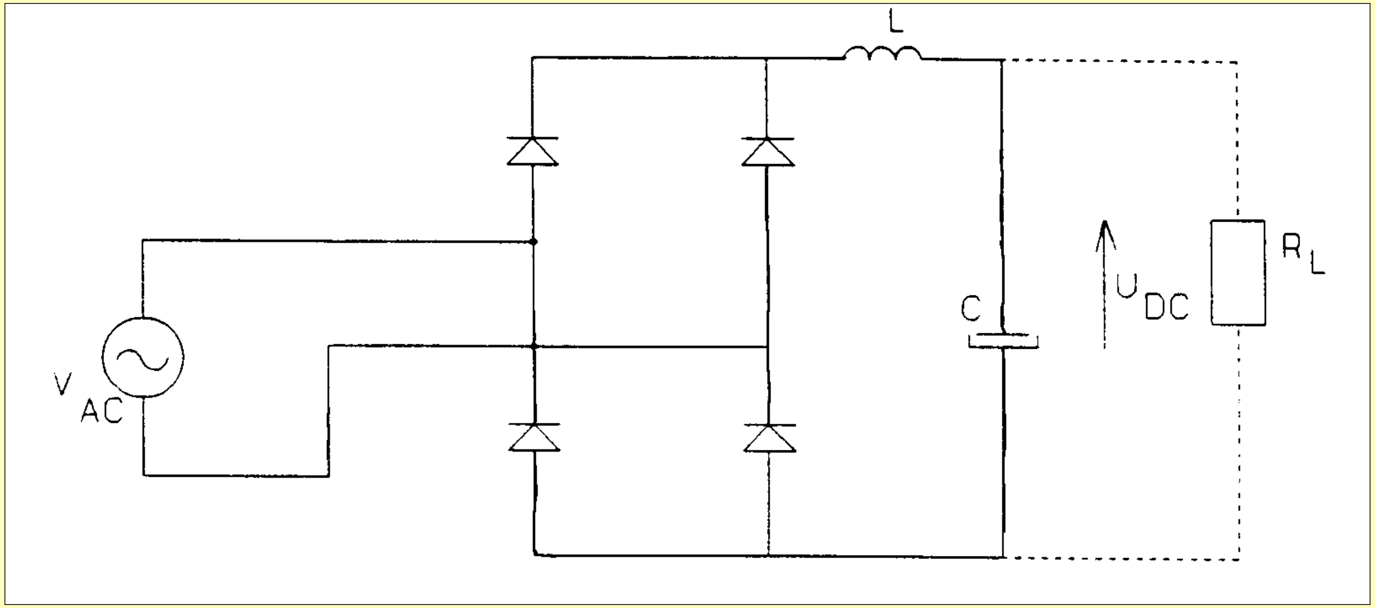
+ the use filters for improvement

4. Filters (AC & DC)

DC-filters

- Filter out DC-voltage and current
- Designed to work in different working points
- Goal is lowest ripple as possible
  - ⇒ Large in physical size
  - ⇒ Very expensive

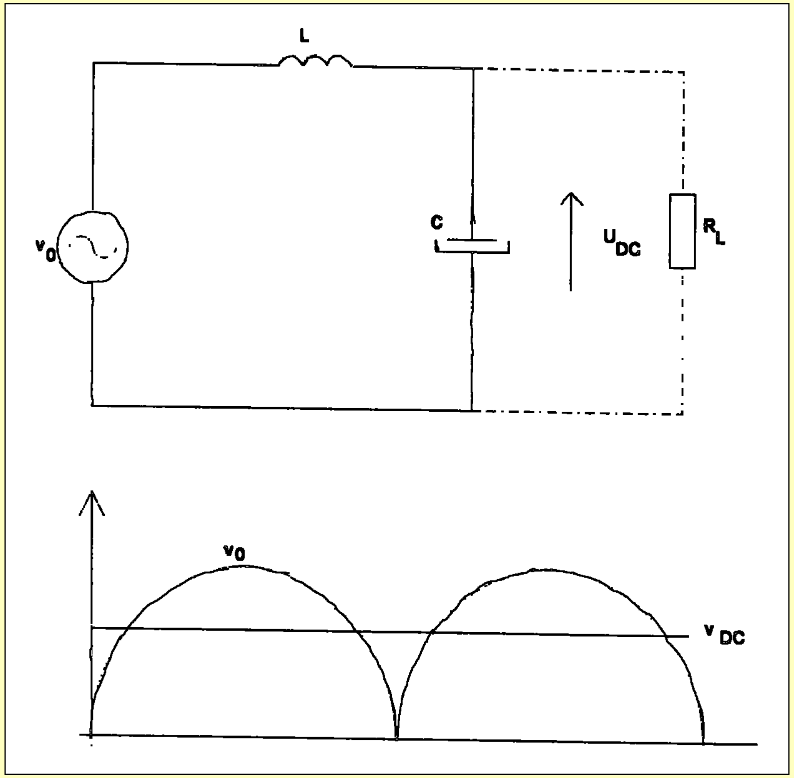
Circuit



Can be considered as an simple low-pass filter

4. Filters (AC & DC)

Model



A method to design could be

- A wish to damp v_0 (AC-component) as much as possible 20 → 40 dB (10-100 times)
  - ⇒ A very low ripple voltage in U_{DC}
  - ⇒ Check that the LC-filter resonance is not excitated by the line ($n \cdot f_{line}$)

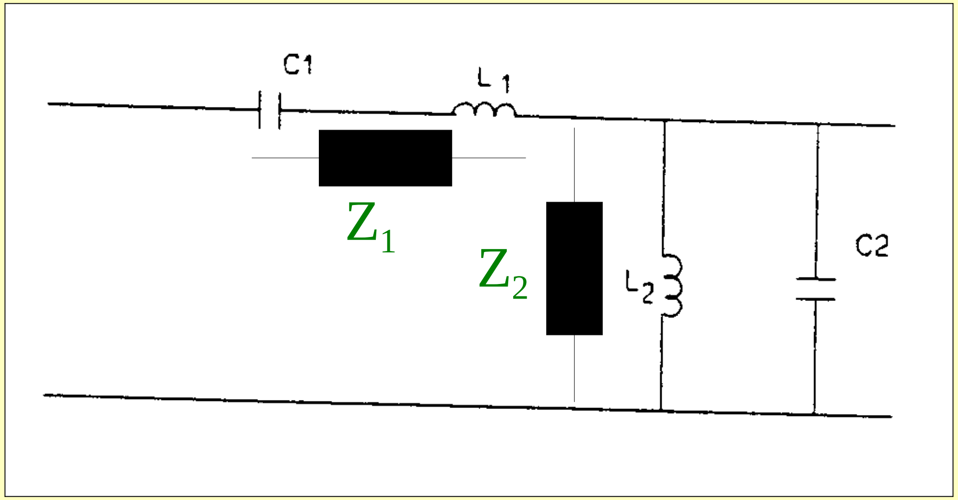
4. Filters (AC & DC)

AC-filters

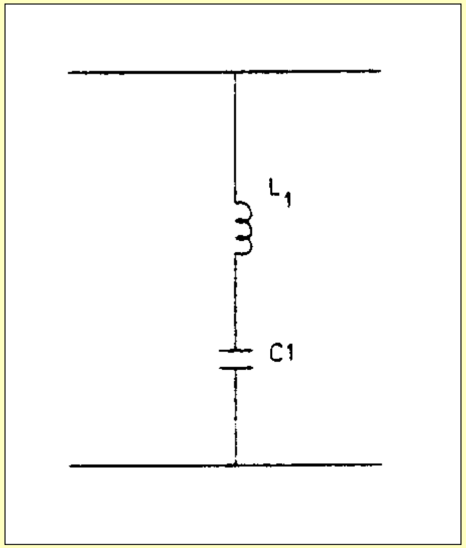
- To give an alternative way for current/voltage harmonics
- Frequency depend (50/60 Hz line)
  - ⇒ Again large in physical size
  - ⇒ Very expensive and additional losses
  - ⇒ Large circulating currents

Different types

Series parallel filter (voltage filter)



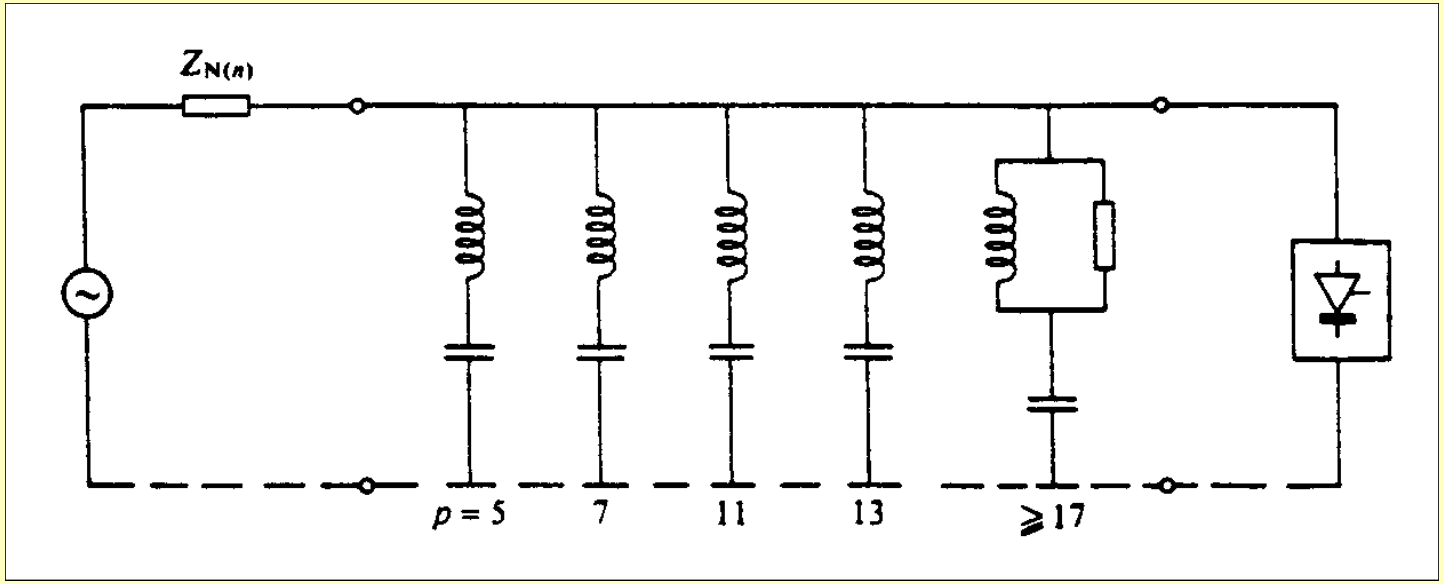
Series resonance filter (current filter)



One frequency matched to a short circuit

4. Filters (AC & DC)

Example



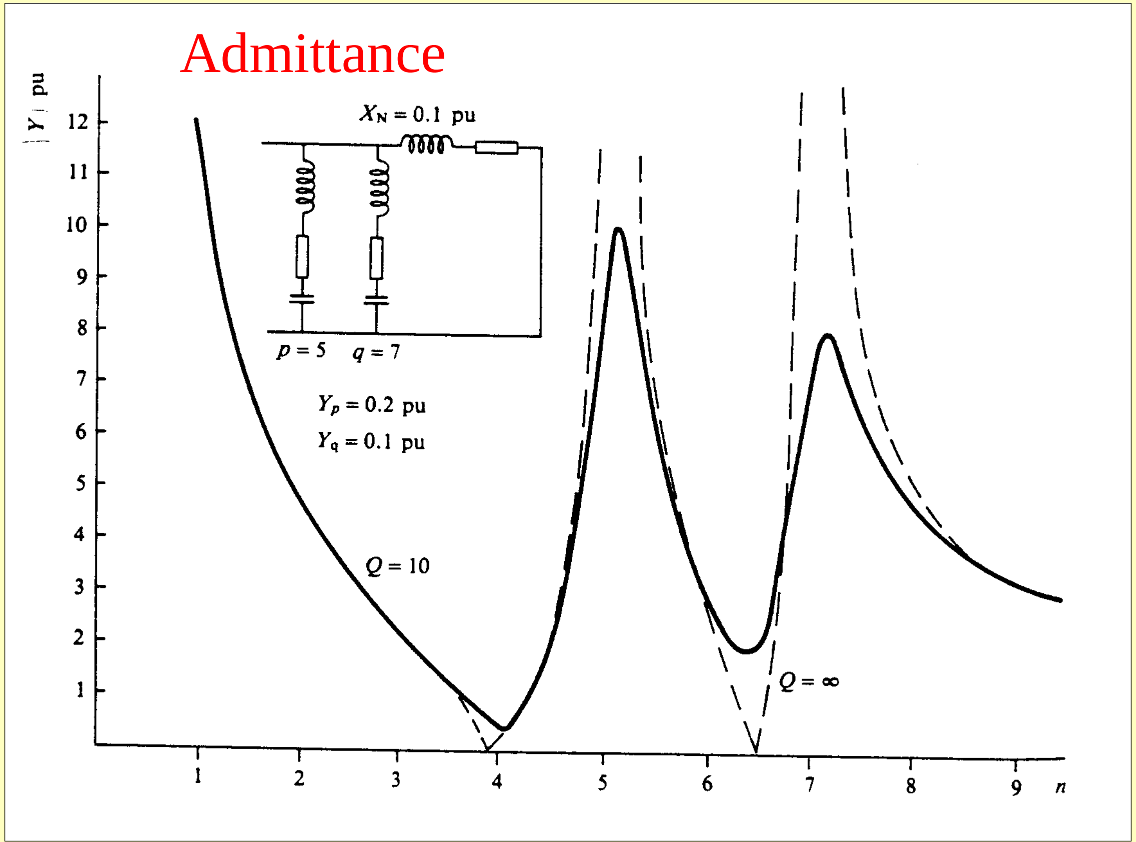
Principle :

Each individual filter is turned to each harmonic (L, C)

lots of no-load losses

4. Filters (AC & DC)

Example of a filter characteristics



$$\mathbf{Y} = \frac{1}{1/(jnY_r) + 1/[rY_r + (r^2Y_r)/(jn)]} = rY_r \frac{1 + j(r/n)^3}{(r/n)^4 - (r/n)^2 + 1}$$

5. Standard & Norms

- New standard and norms comes from time to time (voltage/current)
- Different frequency ranges
- Different power ranges

IEEE-519

Short circuiting current

I_{SC}/I_1	Odd Harmonic Order h (%) $h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	Total Harmonic Distortion (%)
<20	4.0	2.0	1.5	0.6	0.3	5.0
20–50	7.0	3.5	2.5	1.0	0.5	8.0
50–100	10.0	4.5	4.0	1.5	0.7	12.0
100–1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

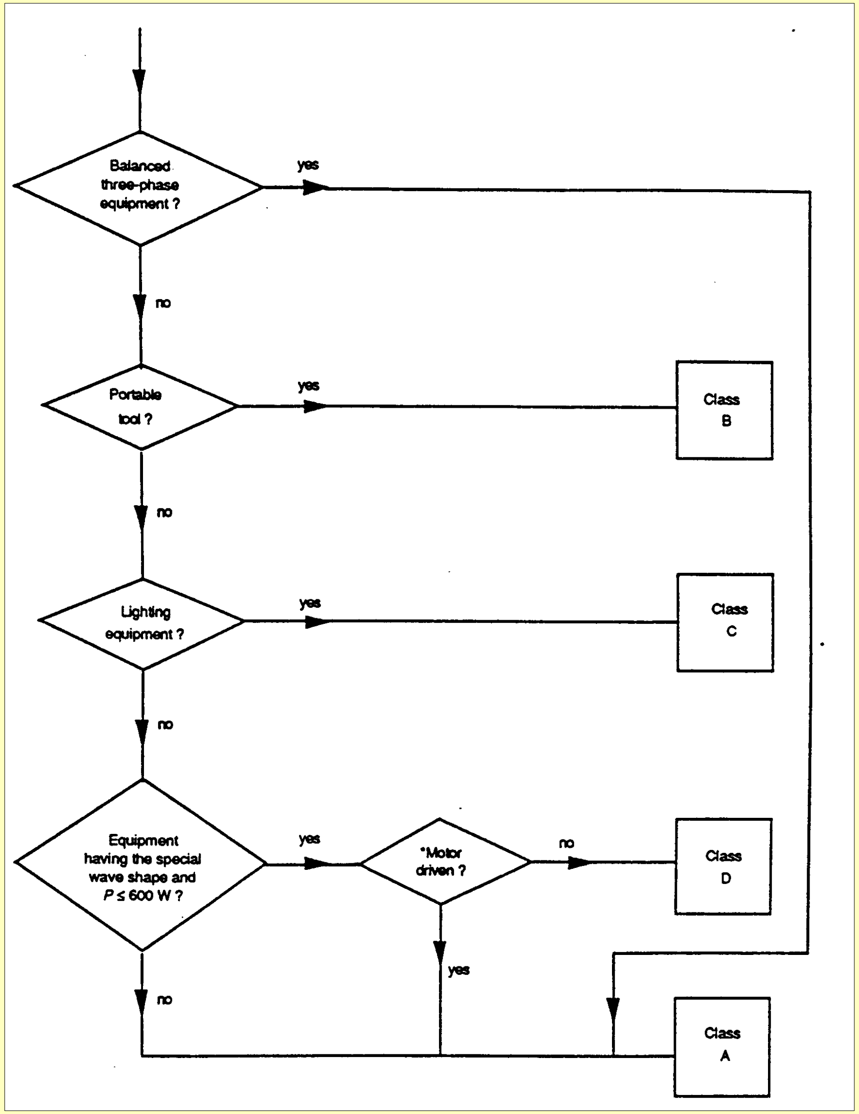
Note: Harmonic current limits for nonlinear load connected to a public utility at the point of common coupling (PCC) with other loads at voltages of 2.4–69 kV. I_{sc} is the maximum short-circuit current at PCC. I_1 is the maximum fundamental-frequency load current at PCC. Even harmonics are limited to 25% of the odd harmonic limits above.

Source: Reference 1.

5. Standard & Norms

IEC-1000-3-2

Finding the class of the equipment



IEC-1000-3-2

5. Standard & Norms

Table 1 – Limits for Class A equipment

Harmonic order n	Maximum permissible harmonic current A
Odd harmonics	
3	2,30
5	1,14
7	0,77
9	0,40
11	0,33
13	0,21
$15 \le n \le 39$	$0,15 \frac{15}{n}$
Even harmonics	
2	1,08
4	0,43
6	0,30
$8 \le n \le 40$	$0,23 \frac{8}{n}$

3 phase load (- special cases)

Table 2 – Limits for Class C equipment

Harmonic order n	Maximum permissible harmonic currrent expressed as a percentage of the input current at the fundamental frequency %
2	2
3	$30 \cdot \lambda$ *
5	10
7	7
9	5
$11 \le n \le 39$ (odd harmonics only)	3

* λ is the circuit power factor

Light equipment

3

Table 3 – Limits for Class D equipment

Harmonic order n	Maximum permissible harmonic current per watt mA/W	Maximum permissible harmonic current A
3	3,4	2,30
5	1,9	1,14
7	1,0	0,77
9	0,5	0,40
11	0,35	0,33
$13 \le n \le 39$ (odd harmonics only)	$\frac{3,85}{n}$	See table 1

Special curve shapes (diode rectifier)

+ Other
IEC-1000-3-4 (>16 A)

6. Exercises

Look at Course home-page