# Formulário de Apoio

### Condensador

$$v_C(t) = v_C(t_0) + \frac{1}{C}\int_{t_0}^{t} i_C(\tau)d\tau$$

$$i_C(t) = C\frac{\partial v_C(t)}{\partial t}$$

Carga e descarga de C com $R$ e $V_S$ constante

$$v_C(t) = V_S + (v_C(t_0) - V_S)\mathrm{e}^{-\frac{t-t_0}{RC}}$$

### Bobine

$$i_L(t) = i_L(t_0) + \frac{1}{L}\int_{t_0}^{t} v_L(\tau)d\tau$$

$$v_L(t) = L\frac{\partial i_L(t)}{\partial t}$$

Carga e descarga de L com $R$ e $V_S$ constante

$$i_L(t) = \frac{V_S}{R} + \left(i_L(t_0) - \frac{V_S}{R}\right)\mathrm{e}^{-\frac{R(t-t_0)}{L}}$$

### Filtros

Filtro Passa-Baixo RC:

$$G = \frac{1}{\sqrt{\left(\frac{f}{f_c}\right)^2 + 1}} \qquad f_c = \frac{1}{2\pi RC}$$

$$G = \frac{1}{\sqrt{1 + (2\pi fRC)^2}}$$

Filtro Passa-Baixo LC:

$$f_c = \frac{1}{2\pi\sqrt{LC}}$$

$$L \leq \frac{0.03V_{DC}}{2\pi f I_{o_{\max}}} \qquad C = \frac{1}{4\pi^2 f_c^2 L}$$

### Conversão AC-DC

$$V_S = \frac{N_S}{N_P}V_P$$

$$I_S = \frac{N_P}{N_S}I_P$$

$$V_{o_{\text{ripple}}} \approx \frac{I_C}{nfC}, \quad n = 1, 2, 3 \text{ ou } 6$$

### Circuitos de proteção

Limitador de corrente:

$$I_{o_{\max}} = \frac{V_{BE_{2_{\text{ON}}}}}{R_S}$$

$$P_{Q_{1\max}} = \left(V_C + V_{BE_{2_{\text{ON}}}} - V_o\right)I_{o_{\max}}$$

Foldback:

$$I_{o_{\max}} = \frac{R_3 + R_4}{R_4 R_S}V_{BE_{2_{\text{ON}}}} + \frac{R_3}{R_4 R_S}V_o$$

### Transístor BJT

Região Ativa:

$$I_E = I_C + I_B$$

$$I_C = \beta I_B$$

$I_E \approx I_C$ para $\beta$ elevado

Região de Saturação:

$$R_{CE} = \frac{|V_{CE_{\text{sat}}}|}{\beta I_B}$$

Potência Dissipada:

$$P_D = |V_{CE}|I_E$$

### Transístor MOSFET

Região de Saturação:

$$I_D = k\left(V_{GS} - V_{GS_{\text{th}}}\right)^2$$

$$k = \frac{I_{D_{\text{ON}}}}{\left(V_{GS_{\text{ON}}} - V_{GS_{\text{th}}}\right)^2}$$

Região Óhmica:

$$R_{DS} = \frac{1}{k\left|V_{GS} - V_{GS_{\text{th}}}\right|}$$

$$V_{DS_{\text{sat}}} = V_{GS} - V_{GS_{\text{th}}}$$

Potência Dissipada:

$$P_D = |V_{DS}|I_D$$

### Transístor IGBT

Região Ativa:

$$I_C = k\left(V_{GE} - V_{GE_{\text{th}}}\right)^2$$

$$k = \frac{I_{C_{\text{ON}}}}{\left(V_{GE_{\text{ON}}} - V_{GE_{\text{th}}}\right)^2}$$

Região Óhmica:

$$R_{CE} = \frac{1}{k\left|V_{GE} - V_{GE_{\text{th}}}\right|}$$

$$V_{CE_{\text{sat}}} = V_{GE} - V_{GE_{\text{th}}} + 0.7$$

Potência Dissipada:

$$P_D = |V_{CE}|I_C$$

**PWM**

$$f = \frac{1}{T} \qquad D = \frac{T_{ON}}{T}$$

$$T = T_{ON} + T_{OFF}$$

Harmónicos:

$$f_h = hf$$

$$V_h = \begin{cases} DV_{ON}, & h = 0 \\ \frac{2V_{ON}}{h\pi} \left|\sin\left(h\pi D\right)\right|, & h > 0 \end{cases}$$

Motor DC:

$$V_E = k\omega$$

$$I_L = \frac{DV_{ON} - V_E}{R_M + R_{CE/DS}}$$

$$I_{L_{ripple}} = \frac{D(1-D)V_{ON}}{fL_M}$$

**Conversores DC-DC**

Buck:

$$V_O = DV_S$$

$$\Delta I_L = \frac{(1-D)V_O}{fL}$$

$$L > \frac{(1-D)V_O}{2fI_O} \qquad C > \frac{(1-D)V_O}{8f^2 LV_{O_{ripple}}}$$

Boost:

$$V_O = \frac{V_S}{1-D}$$

$$\Delta I_L = \frac{D(1-D)V_O}{fL}$$

$$L > \frac{D(1-D)^2 V_O}{2fI_O} \qquad C > \frac{DI_O}{fV_{O_{ripple}}}$$

Buck-Boost:

$$V_o = -\frac{DV_S}{1-D}$$

$$\Delta I_L = -\frac{(1-D)V_O}{fL}$$

$$L > -\frac{(1-D)^2 V_O}{2fI_O} \qquad C > \frac{DI_O}{fV_{O_{ripple}}}$$

Flyback:

$$V_o = \frac{N_S}{N_P} \times \frac{DV_S}{1-D}$$

$$\Delta I_L = \frac{N_P}{N_S} \times \frac{(1-D)V_O}{fL_P}$$

$$L > \left(\frac{N_P}{N_S}\right)^2 \times \frac{(1-D)^2 V_O}{2fI_O}$$

$$C > \frac{DI_O}{fV_{O_{ripple}}}$$

**Inversores**

Onda Quadrada:

$$f_h = hf$$

$$V_{o_h} = \frac{4V_{DC}}{h\pi}\left|\sin\left(\frac{h\pi}{2}\right)\right|$$

Onda Sinusoidal Modificada:

$$f_h = hf$$

$$V_{o_h} = \frac{4V_{DC}}{h\pi\sqrt{2}}\left|\sin\left(\frac{h\pi}{2}\right)\right|$$

SPWM:

$$m_f = \frac{f_\Delta}{f_C}$$

$$m_a = \frac{V_C}{V_\Delta}$$

$$f_h = hf_C$$

$h = lm_f \pm k$ onde:

$k = 1, 3, 5, \ldots$ para $l = 2, 4, 6, \ldots$

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$$V_{O_1} = m_a V_{DC}$$

**Modelo Térmico**

Regime permanente:

$$T_x - T_y = P_D\theta_{xy}$$

| $l$ | $h$ \ $m_a$ | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 |
| 1 | $m_f$ | 1.265 | 1.242 | 1.204 | 1.151 | 1.084 | 1.006 | 0.916 | 0.818 | 0.712 | 0.601 |
| | $m_f \pm 2$ | 0.004 | 0.015 | 0.035 | 0.061 | 0.093 | 0.131 | 0.174 | 0.220 | 0.268 | 0.318 |
| | $m_f \pm 4$ | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.003 | 0.004 | 0.008 | 0.012 | 0.018 |
| 2 | $2m_f \pm 1$ | 0.099 | 0.190 | 0.268 | 0.326 | 0.361 | 0.370 | 0.354 | 0.314 | 0.255 | 0.181 |
| | $2m_f \pm 3$ | 0.000 | 0.003 | 0.011 | 0.024 | 0.044 | 0.071 | 0.103 | 0.139 | 0.177 | 0.212 |
| | $2m_f \pm 5$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.003 | 0.007 | 0.013 | 0.021 | 0.033 |
| 3 | $3m_f$ | 0.401 | 0.335 | 0.238 | 0.123 | 0.011 | 0.083 | 0.146 | 0.171 | 0.157 | 0.113 |
| | $3m_f \pm 2$ | 0.012 | 0.044 | 0.089 | 0.138 | 0.180 | 0.204 | 0.203 | 0.176 | 0.127 | 0.062 |
| | $3m_f \pm 4$ | 0.000 | 0.001 | 0.004 | 0.012 | 0.026 | 0.047 | 0.074 | 0.104 | 0.134 | 0.157 |
| | $3m_f \pm 6$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.003 | 0.008 | 0.016 | 0.028 | 0.044 |
| 4 | $4m_f \pm 1$ | 0.095 | 0.163 | 0.185 | 0.157 | 0.091 | 0.008 | 0.064 | 0.105 | 0.105 | 0.068 |
| | $4m_f \pm 3$ | 0.002 | 0.012 | 0.036 | 0.070 | 0.106 | 0.132 | 0.137 | 0.115 | 0.068 | 0.009 |
| | $4m_f \pm 5$ | 0.000 | 0.000 | 0.002 | 0.006 | 0.017 | 0.034 | 0.058 | 0.084 | 0.107 | 0.119 |
| | $4m_f \pm 7$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.003 | 0.008 | 0.017 | 0.032 | 0.050 |