# Inversor de Voltaje Trifásico



**Problema** Estudiar el inversor de voltaje con Modulación SPWM.

La moduladora es, $M := 0.9 \quad \omega_s := 2\cdot\pi\cdot 50 \quad f_M := 0$

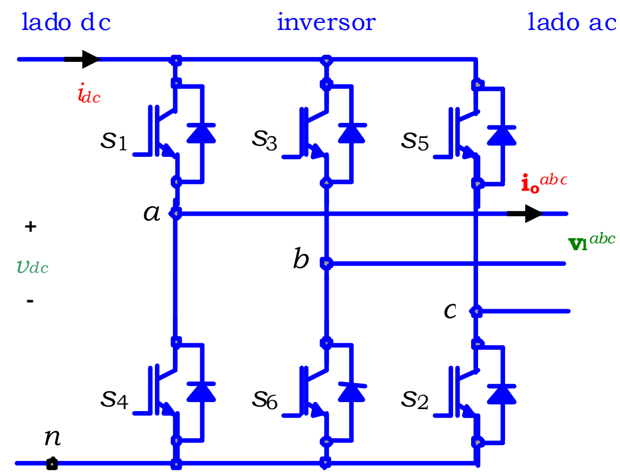
$$m_a(t,M) := M\cdot\sin\left(\omega_s\cdot t + f_M - \frac{0\cdot\pi}{3}\right)$$

$$m_b(t,M) := M\cdot\sin\left(\omega_s\cdot t + f_M - \frac{2\cdot\pi}{3}\right)$$

$$m_c(t,M) := M\cdot\sin\left(\omega_s\cdot t + f_M - \frac{4\cdot\pi}{3}\right)$$

La triangular es, $f_{n\_tr} := 15 \quad per := 1$

$$tri(t) := \frac{2}{\pi}\cdot asin\left(\sin\left(f_{n\_tr}\cdot\omega_s\cdot t + f_M\cdot f_{n\_tr} - \pi\right)\right)$$



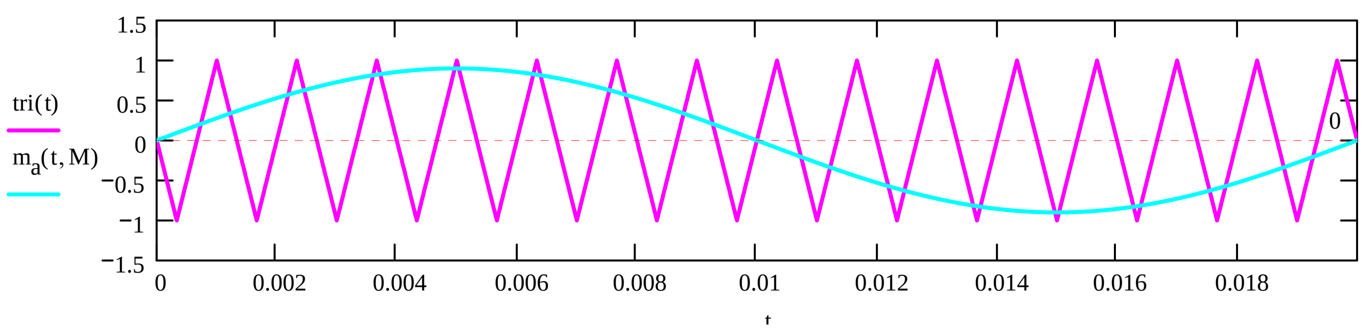

Las conmutaciones,

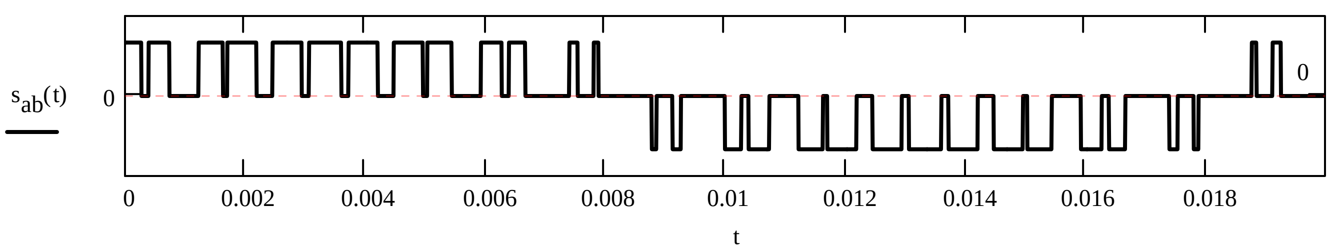
$s_1(t) := if(m_a(t,M) > tri(t),1,0)$ $\quad s_4(t) := if(m_a(t,M) > tri(t),0,1)$

$s_3(t) := if(m_b(t,M) > tri(t),1,0)$ $\quad s_6(t) := if(m_a(t,M) > tri(t),0,1)$

$s_5(t) := if(m_c(t,M) > tri(t),1,0)$ $\quad s_2(t) := if(m_c(t,M) > tri(t),0,1)$

$n_f := f_{n\_tr}\cdot 4\cdot 50\cdot per \quad n := 0..n_f \quad t_f := .02\cdot per \quad t := 0, \frac{t_f}{n_f}..t_f$




Los voltajes se pueden escribir como,

$v_{an}(t) = s_1(t)\cdot v_{dc}(t)$ $\quad v_{bn}(t) = s_3(t)\cdot v_{dc}(t)$

$v_{l\_ab}(t) = v_{an}(t) - v_{bn}(t)$

$v_{l\_ab}(t) = s_1(t)\cdot v_{dc}(t) - s_3(t)\cdot v_{dc}(t)$

$v_{l\_ab}(t) = (s_1(t) - s_3(t))\cdot v_{dc}(t)$

$v_{l\_ab}(t) = s_{ab}(t)\cdot v_{dc}(t)$

Se define la función de conmutación como,

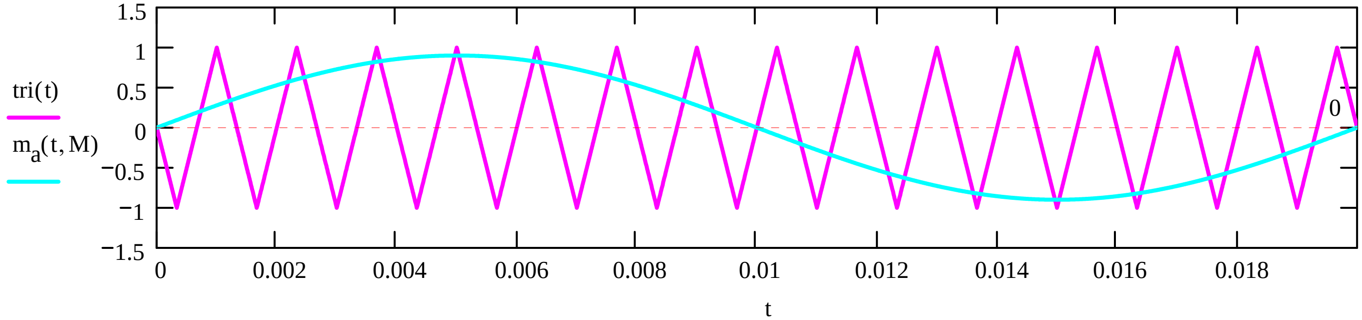
$s_{ab}(t) := s_1(t) - s_3(t)$

$s_{bc}(t) := s_3(t) - s_5(t)$

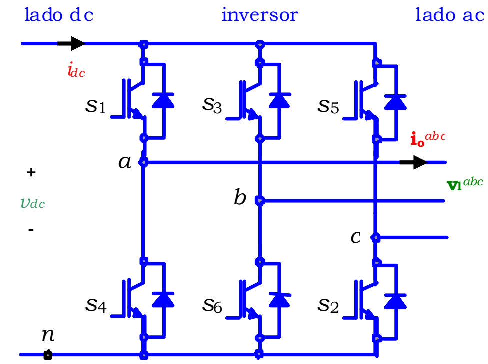
$s_{ca}(t) := s_5(t) - s_1(t)$

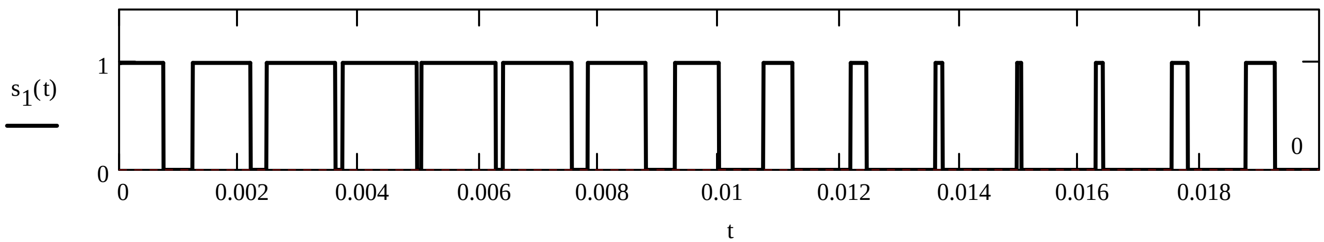
$v_{l\_bc}(t) = s_{bc}(t)\cdot v_{dc}(t)$

$v_{l\_ca}(t) = s_{ca}(t)\cdot v_{dc}(t)$



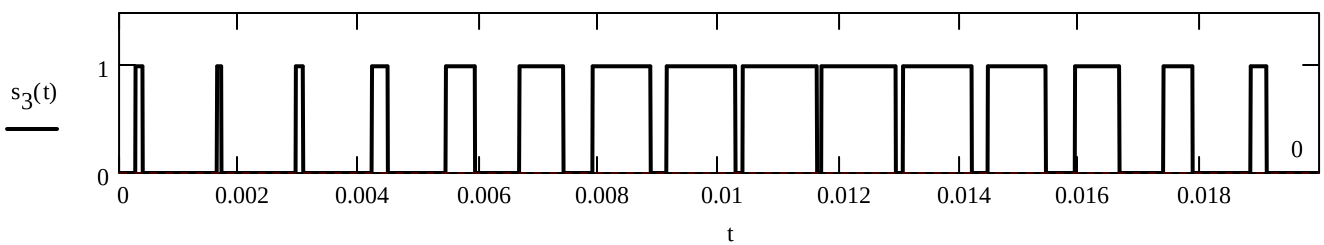


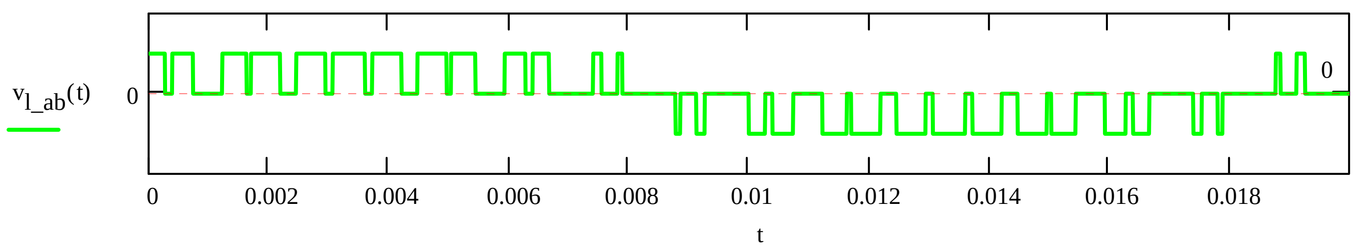




$s_{ab}(t) := s_1(t) - s_3(t)$ $\quad V_{dc} := 500$

$v_{dc}(t) := V_{dc}$ $\quad v_{l\_ab}(t) := s_{ab}(t) \cdot v_{dc}(t)$



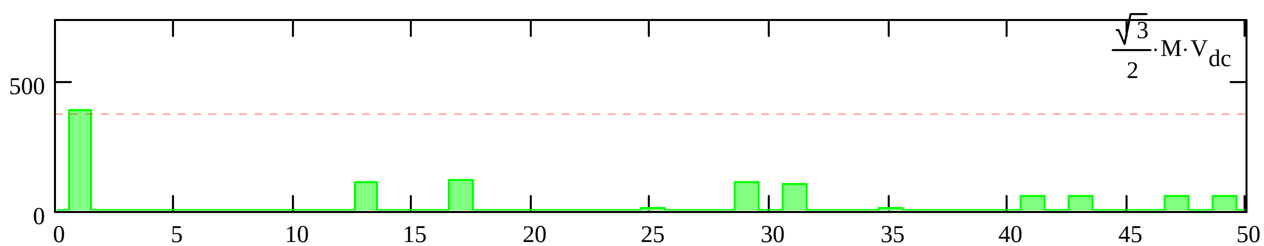

$N := 1024 \qquad m := 1..N$

$x_m := v_{l\_ab}\left(\frac{m}{N} \cdot t_f\right) \qquad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2) \cdot xf_{m \cdot per}$

$|xv(2)| = 390.691 \qquad \frac{\sqrt{3}}{2} \cdot M \cdot V_{dc} = 389.711$

**FFT de $v_{l\_ab}$**




**La fundamental del voltaje ac es igual a $0.866MV_{dc}$ y no hay componentes de frecuencia hasta $f_{n\_tr}$ / 2.**

**Otra Modulación SPWM**

$M := 1.05$

$sup(t) := if\left(m_a(t,M) > m_b(t,M), if\left(m_a(t,M) > m_c(t,M), m_a(t,M), m_c(t,M)\right), if\left(m_b(t,M) > m_c(t,M), m_b(t,M), m_c(t,M)\right)\right)$

$inf(t) := if\left(m_a(t,M) < m_b(t,M), if\left(m_a(t,M) < m_c(t,M), m_a(t,M), m_c(t,M)\right), if\left(m_b(t,M) < m_c(t,M), m_b(t,M), m_c(t,M)\right)\right)$

$seq_0(t) := (sup(t) + inf(t)) \cdot \frac{1}{3}$

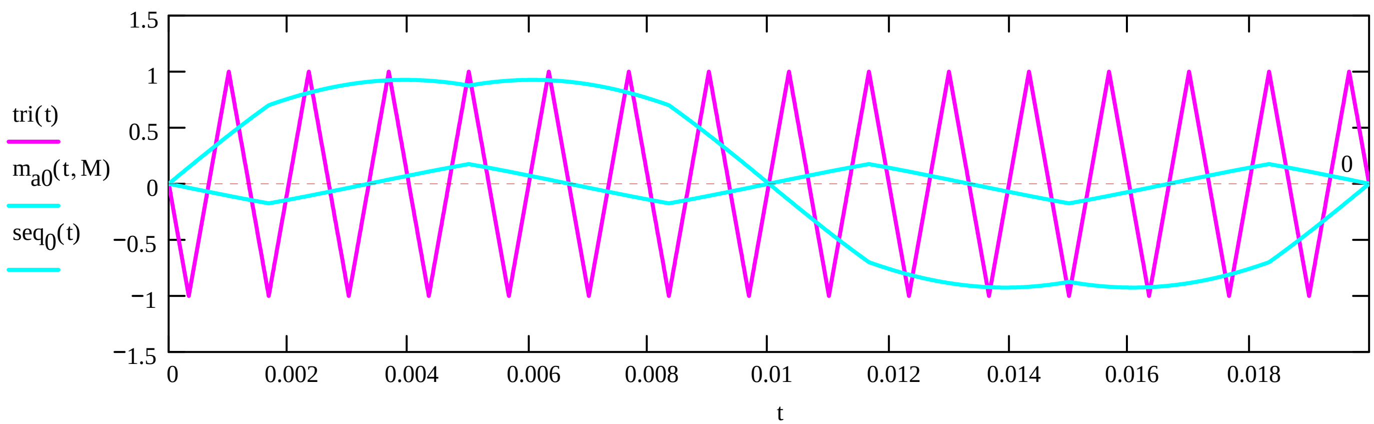
$m_{a0}(t,M) := m_a(t,M) - seq_0(t)$ $\quad m_{b0}(t,M) := m_b(t,M) - seq_0(t)$ $\quad m_{c0}(t,M) := m_c(t,M) - seq_0(t)$

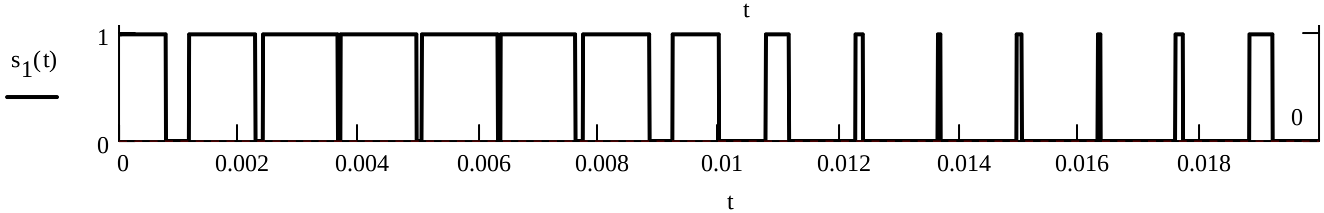
$s_1(t) := if\left(m_{a0}(t,M) > tri(t), 1, 0\right)$ $\quad s_3(t) := if\left(m_{b0}(t,M) > tri(t), 1, 0\right)$ $\quad s_5(t) := if\left(m_{c0}(t,M) > tri(t), 1, 0\right)$

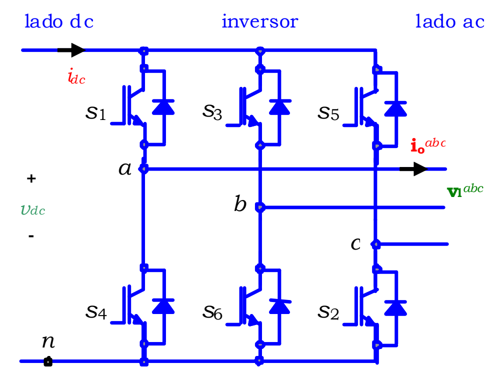
$s_{ab}(t) := s_1(t) - s_3(t)$

$s_{bc}(t) := s_3(t) - s_5(t)$

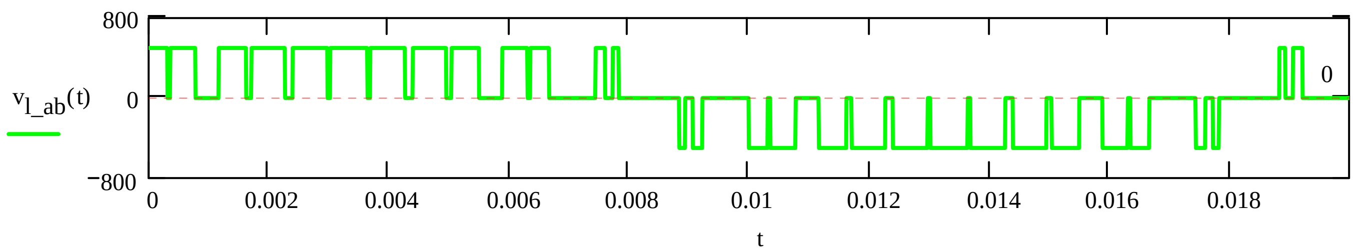
$s_{ca}(t) := s_5(t) - s_1(t)$




$v_{l\_ab}(t) := s_{ab}(t) \cdot v_{dc}(t)$



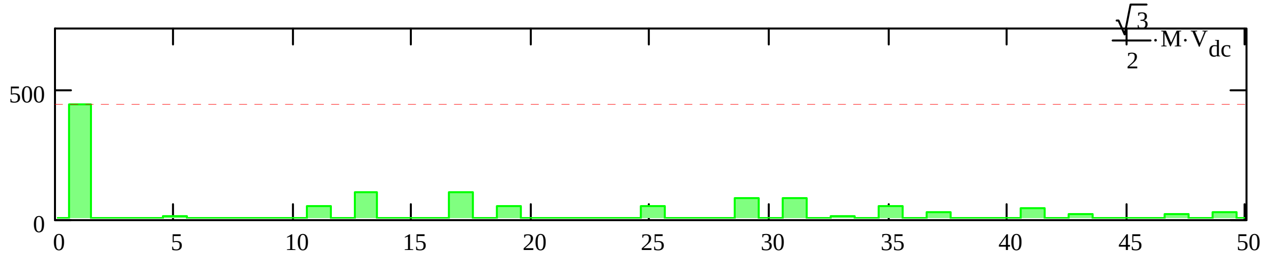

$N := 1024 \qquad m := 1..N$

$x_m := v_{l\_ab}\left(\frac{m}{N} \cdot t_f\right) \qquad xf := FFT(x)$

$xv(m) := if(m = 1, 1, 2) \cdot xf_{m \cdot per}$

$|xv(2)| = 450.01 \qquad \frac{\sqrt{3}}{2} \cdot M \cdot V_{dc} = 454.663$

**FFT de $v_{l\_ab}$**

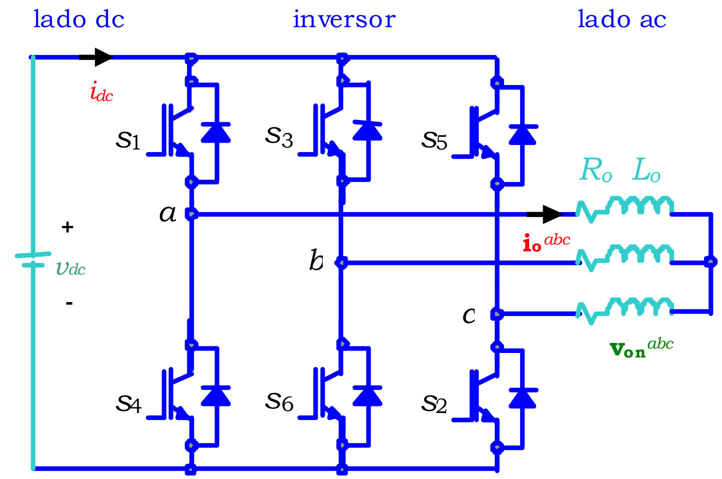



**La fundamental del voltaje ac es igual a $0.866MV_{dc}$ y no hay componentes de frecuencia hasta $f_{n\_tr}$ / 2. M puede llegar a ser 1.17**

# Modelo de Inversor de Voltaje Trifásico



**Problema** Estudiar el modelo del inversor de voltaje con Modulación SPWM.




La suma de las corrientes de carga es cero y la carga es balanceada, entonces,

$$v_{o\_an}(t) + v_{o\_bn}(t) + v_{o\_cn}(t) = 0$$

$$v_{l\_ab}(t) = s_{ab}(t)\cdot v_{dc}(t) = (s_1(t) - s_3(t))\cdot v_{dc}(t)$$

$$v_{l\_bc}(t) = s_{bc}(t)\cdot v_{dc}(t) = (s_3(t) - s_5(t))\cdot v_{dc}(t)$$

$$v_{l\_ca}(t) = s_{ca}(t)\cdot v_{dc}(t) = (s_5(t) - s_1(t))\cdot v_{dc}(t)$$

por lo tanto,

$$\begin{pmatrix} v_{l\_ab}(t) \\ v_{l\_bc}(t) \\ 0 \end{pmatrix} = \begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 1 & 1 \end{pmatrix} \cdot \begin{pmatrix} v_{o\_an}(t) \\ v_{o\_bn}(t) \\ v_{o\_cn}(t) \end{pmatrix} \qquad \begin{pmatrix} v_{o\_an}(t) \\ v_{o\_bn}(t) \\ v_{o\_cn}(t) \end{pmatrix} = \frac{1}{3}\cdot \begin{pmatrix} 2 & 1 & 1 \\ -1 & 1 & 1 \\ -1 & -2 & 1 \end{pmatrix} \cdot \begin{pmatrix} v_{l\_ab}(t) \\ v_{l\_bc}(t) \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} v_{o\_an}(t) \\ v_{o\_bn}(t) \\ v_{o\_cn}(t) \end{pmatrix} = \frac{1}{3}\cdot \begin{pmatrix} 2 & 1 & 1 \\ -1 & 1 & 1 \\ -1 & -2 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} s_1(t) \\ s_3(t) \\ s_5(t) \end{pmatrix} \cdot v_{dc}(t) = \frac{1}{3}\cdot \begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix} \cdot \begin{pmatrix} s_1(t) \\ s_3(t) \\ s_5(t) \end{pmatrix} \cdot v_{dc}(t)$$

$$v_{o\_an}(t) = R_o\cdot i_{o\_a}(t) + L_o\cdot di_{o\_a}(t)$$

$$v_{o\_bn}(t) = R_o\cdot i_{o\_b}(t) + L_o\cdot di_{o\_b}(t)$$

$$v_{o\_cn}(t) = R_o\cdot i_{o\_c}(t) + L_o\cdot di_{o\_c}(t)$$

$$v_{dc}(t)\cdot i_{dc}(t) = v_{o\_n}(t)^T\cdot i_o(t)$$

$$v_{o\_n}(t) = T_{ln}\cdot s_i(t)\cdot v_{dc}(t)$$

$$T_{ln} := \frac{1}{3}\cdot \begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix} \qquad T_{ln}^T = T_{ln} \qquad s_i(t) := \begin{pmatrix} s_1(t) \\ s_3(t) \\ s_5(t) \end{pmatrix}$$

$$v_{dc}(t)\cdot i_{dc}(t) = (T_{ln}\cdot s_i(t)\cdot v_{dc}(t))^T\cdot i_o(t)$$

$$i_{dc}(t) = s_i(t)^T\cdot T_{ln}^T\cdot i_o(t)$$

$$T_{ln}\cdot s_i(t)\cdot v_{dc}(t) = R_o\cdot i_o(t) + L_o\cdot di_o(t)$$

$$i_{dc}(t) = s_i(t)^T\cdot T_{ln}\cdot i_o(t)$$

$$di_o(t) = \frac{-R_o}{L_o}\cdot i_o(t) + \frac{1}{L_o}\cdot T_{ln}\cdot s_i(t)\cdot v_{dc}(t)$$

Parámetros

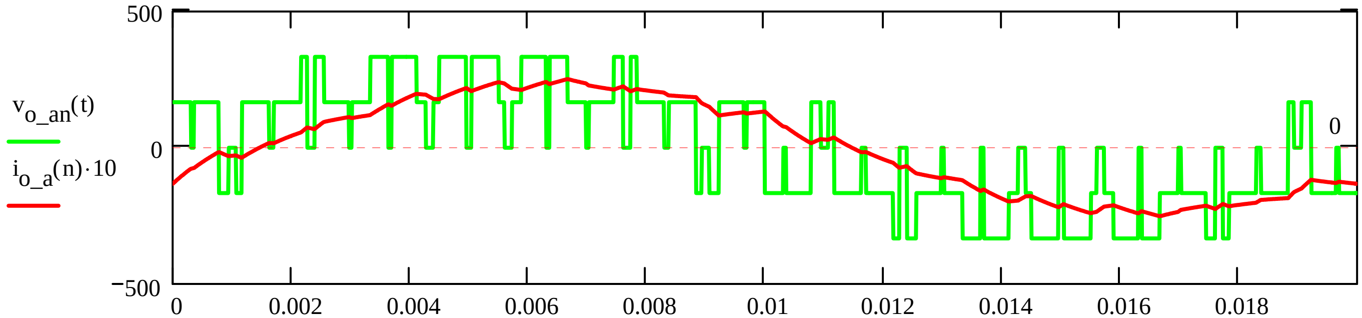
$$L_o := 15\cdot 10^{-3} \qquad R_o := 10 \qquad v_{dc}(t) := V_{dc}$$

Simulación $\quad t_f := 0.02 \quad n_f := 2048 \quad n := 1..n_f \quad t := 0, \frac{t_f}{n_f}..t_f$

$$D(t,x) := \frac{-R_o}{L_o}\cdot (x_1\ \ x_2\ \ x_3)^T + \frac{1}{L_o}\cdot T_{ln}\cdot s_i(t)\cdot v_{dc}(t) \qquad CI := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \qquad Z := \mathrm{rkfixed}(CI, 0, t_f, n_f, D) \qquad CI := (Z_{n_f,2}\ \ Z_{n_f,3}\ \ Z_{n_f,4})^T \qquad Z := \mathrm{rkfixed}(CI, 0, t_f, n_f, D)$$

$v_{o\_an}(t) := \left(T_{ln} \cdot s_i(t) \cdot v_{dc}(t)\right)_1$ $\quad v_{o\_bn}(t) := \left(T_{ln} \cdot s_i(t) \cdot v_{dc}(t)\right)_2$ $\quad v_{o\_cn}(t) := \left(T_{ln} \cdot s_i(t) \cdot v_{dc}(t)\right)_3$

$i_{o\_a}(n) := Z_{n,2}$ $\quad i_{o\_b}(n) := Z_{n,3}$ $\quad i_{o\_c}(n) := Z_{n,4}$ $\quad i_{dc}(n) := \left(s_i\left(n \cdot \frac{t_f}{n_f}\right)\right)^T \cdot \left(T_{ln}\right)^T \cdot \left(i_{o\_a}(n) \;\; i_{o\_b}(n) \;\; i_{o\_c}(n)\right)^T$



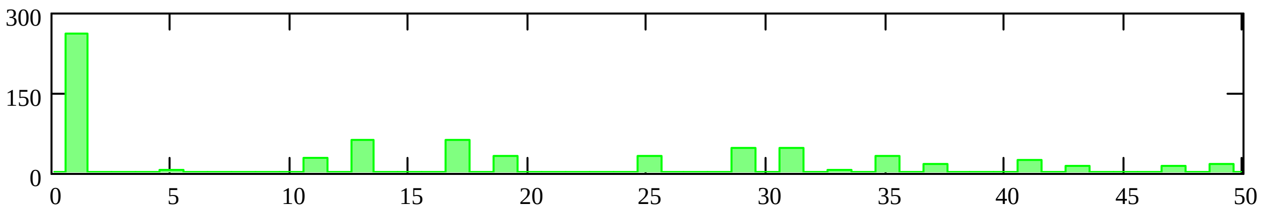

$N := 1024$ $\quad m := 1..N$

$x_m := v_{o\_an}\left(\frac{m}{N} \cdot t_f\right)$ $\quad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2) \cdot xf_{m \cdot per}$

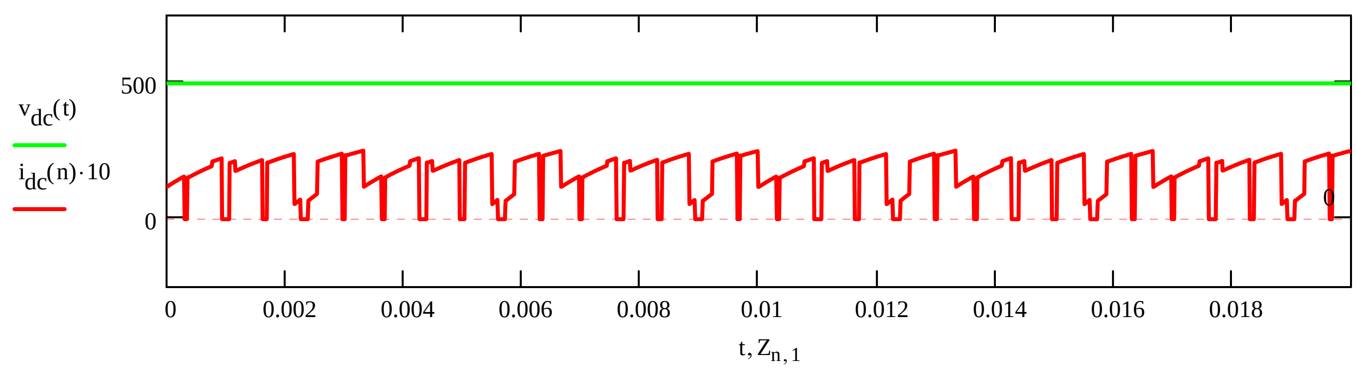
$|xv(2)| = 259.337$ $\quad V_{o\_n\_rms} := \frac{1}{2} \cdot M \cdot \frac{V_{dc}}{\sqrt{2}}$

**FFT de $v_{o\_an}$**




$$v_{o\_an1}(t) = \frac{V_{dc}}{2} \cdot m_a(t) \qquad f \le \frac{f_{n\_tr}}{2}$$

**La fundamental de voltaje de carga es igual a la moduladora sobre 2.**




$$I_{o\_rms} := \frac{1}{2} \cdot M \cdot \frac{V_{dc}}{\sqrt{2}} \cdot \frac{1}{\sqrt{R_o^2 + \left(\omega_s \cdot L_o\right)^2}}$$

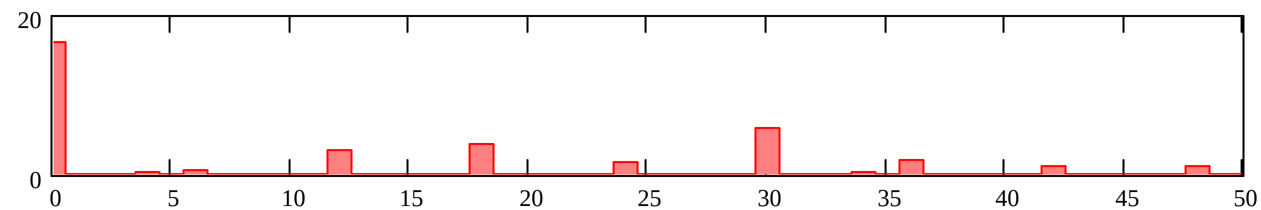
$N := 1024$ $\quad m := 1..N$

$x_m := i_{dc}\left(\frac{m}{N} \cdot n_f\right)$ $\quad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2) \cdot xf_{m \cdot per}$

$|xv(1)| = 16.653$

**FFT de $i_{dc}$**




$$P_o := 3 \cdot V_{o\_n\_rms} \cdot I_{o\_rms} \cdot \cos\left(\operatorname{atan}\left(\omega_s \cdot \frac{L_o}{R_o}\right)\right)$$

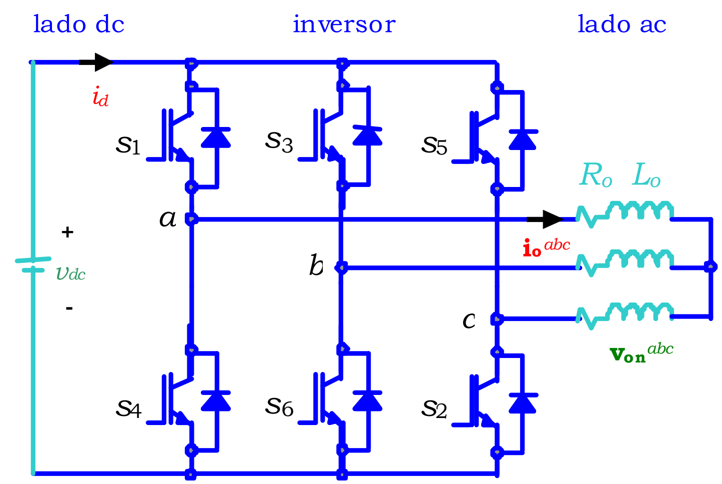
$I_{dc} := \frac{P_o}{V_{dc}}$ $\qquad I_{dc} = 16.916$

**La corriente DC no tiene segunda armónica. Sólo armónicas de conmutación.**

# Modelo Promedio de Inversor de Voltaje Monofásico



**Problema** Estudiar el modelo promedio del inversor de voltaje.




**Se opta por trabajar con la fundamental.**

Como la suma de las corrientes de carga es cero y la carga es balanceada, entonces,

$$v_{o\_an}(t) + v_{o\_bn}(t) + v_{o\_cn}(t) = 0$$

$$\begin{pmatrix} v_{o\_an}(t) \\ v_{o\_bn}(t) \\ v_{o\_cn}(t) \end{pmatrix} = \frac{1}{2}\cdot\begin{pmatrix} m_a(t) \\ m_b(t) \\ m_c(t) \end{pmatrix}\cdot v_{dc}(t)$$

por lo tanto,

$$\begin{pmatrix} v_{l\_ab}(t) \\ v_{l\_bc}(t) \\ v_{l\_ca}(t) \end{pmatrix} = \begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{pmatrix}\cdot\begin{pmatrix} v_{o\_an}(t) \\ v_{o\_bn}(t) \\ v_{o\_cn}(t) \end{pmatrix} = \frac{1}{2}\cdot\begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{pmatrix}\cdot\begin{pmatrix} m_a(t) \\ m_b(t) \\ m_c(t) \end{pmatrix}\cdot v_{dc}(t)$$

$$\begin{pmatrix} v_{l\_ab}(t) \\ v_{l\_bc}(t) \\ v_{l\_ca}(t) \end{pmatrix} = \frac{1}{2}\cdot\begin{pmatrix} m_a(t) - m_b(t) \\ m_b(t) - m_c(t) \\ m_c(t) - m_a(t) \end{pmatrix}\cdot v_{dc}(t) = \begin{pmatrix} m_{ab}(t) \\ m_{bc}(t) \\ m_{ca}(t) \end{pmatrix}\cdot v_{dc}(t)$$

$$v_{o\_an}(t) = R_o\cdot i_{o\_a}(t) + L_o\cdot di_{o\_a}(t)$$

$$v_{o\_bn}(t) = R_o\cdot i_{o\_b}(t) + L_o\cdot di_{o\_b}(t)$$

$$v_{o\_cn}(t) = R_o\cdot i_{o\_c}(t) + L_o\cdot di_{o\_c}(t)$$

$$v_{dc}(t)\cdot i_{dc}(t) = v_{o\_n}(t)^T\cdot i_o(t)$$

$$v_{o\_n}(t) = m_i(t)\cdot v_{dc}(t)$$

$$v_{dc}(t)\cdot i_{dc}(t) = \left(m_i(t)\cdot v_{dc}(t)\right)^T\cdot i_o(t)$$

$$i_{dc}(t) = m_i(t)^T\cdot i_o(t)$$

$$m_i(t) := \frac{1}{2}\cdot\begin{pmatrix} m_a(t,M) \\ m_b(t,M) \\ m_c(t,M) \end{pmatrix}$$

$$m_i(t)\cdot v_{dc}(t) = R_o\cdot i_o(t) + L_o\cdot di_o(t)$$

$$i_{dc}(t) = m_i(t)^T\cdot i_o(t)$$

$$di_o(t) = \frac{-R_o}{L_o}\cdot i_o(t) + \frac{1}{L_o}\cdot m_i(t)\cdot v_{dc}(t)$$

Parámetros

$L_o := 15\cdot 10^{-3}$ $R_o := 10$ $v_{dc}(t) := V_{dc}$

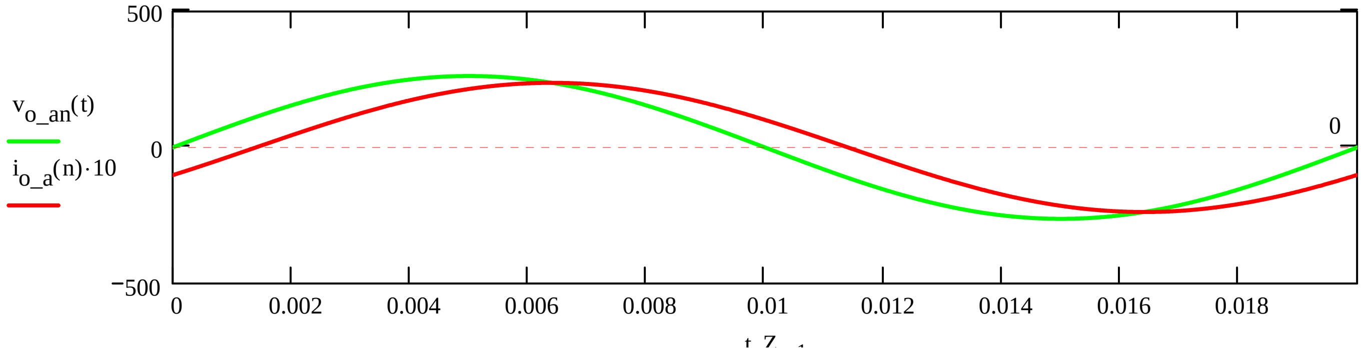
Simulación $t_f := 0.02$ $n_f := 2048$ $n := 1..n_f$ $t := 0, \frac{t_f}{n_f}..t_f$

$$D(t,x) := \frac{-R_o}{L_o}\cdot\left(x_1\ \ x_2\ \ x_3\right)^T + \frac{1}{L_o}\cdot m_i(t)\cdot v_{dc}(t)$$

$CI := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$ $Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$ $CI := \left(Z_{n_f,2}\ \ Z_{n_f,3}\ \ Z_{n_f,4}\right)^T$ $Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

$v_{o\_an}(t) := \left(m_i(t)\cdot v_{dc}(t)\right)_1$ $\qquad v_{o\_bn}(t) := \left(m_i(t)\cdot v_{dc}(t)\right)_2$ $\qquad v_{o\_cn}(t) := \left(m_i(t)\cdot v_{dc}(t)\right)_3$

$i_{o\_a}(n) := Z_{n,2}$ $\qquad i_{o\_b}(n) := Z_{n,3}$ $\qquad i_{o\_c}(n) := Z_{n,4}$ $\qquad i_{dc}(n) := \left(m_i\left(n\cdot\frac{t_f}{n_f}\right)\right)^T\cdot\left(i_{o\_a}(n)\;\; i_{o\_b}(n)\;\; i_{o\_c}(n)\right)^T$




$N := 1024 \qquad m := 1..N$

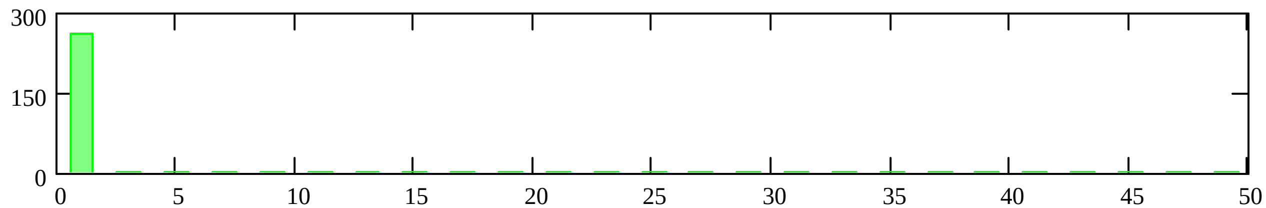
$x_m := v_{o\_an}\left(\frac{m}{N}\cdot t_f\right) \qquad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

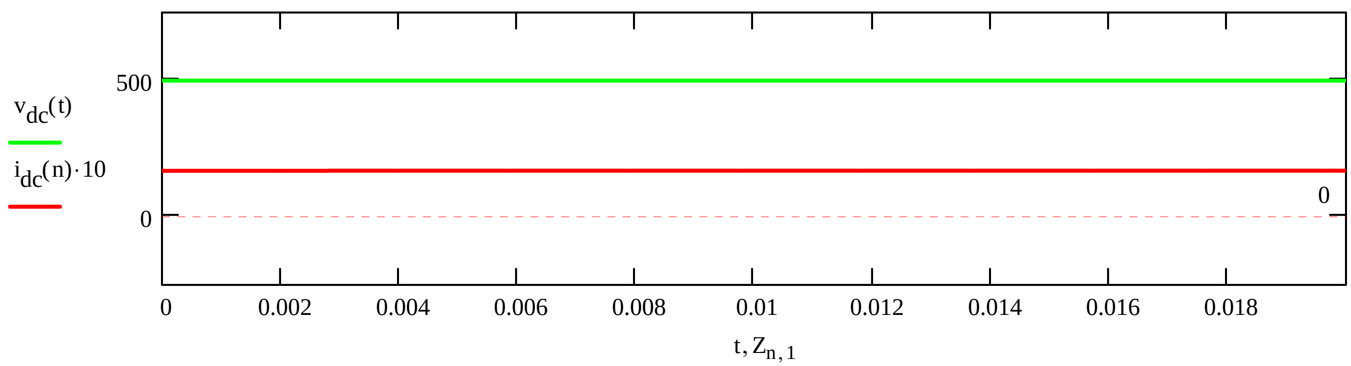
$|xv(2)| = 262.5 \qquad V_{o\_n\_rms} := \frac{1}{2}\cdot M\cdot\frac{V_{dc}}{\sqrt{2}}$

$\frac{1}{2}\cdot M\cdot V_{dc} = 262.5$

**FFT de $v_{o\_an}$**




**La fundamental de voltaje de carga es igual a la moduladora sobre 2.**




$I_{o\_rms} := \frac{1}{2}\cdot M\cdot\frac{V_{dc}}{\sqrt{2}}\cdot\frac{1}{\sqrt{R_o^2 + \left(\omega_s\cdot L_o\right)^2}}$

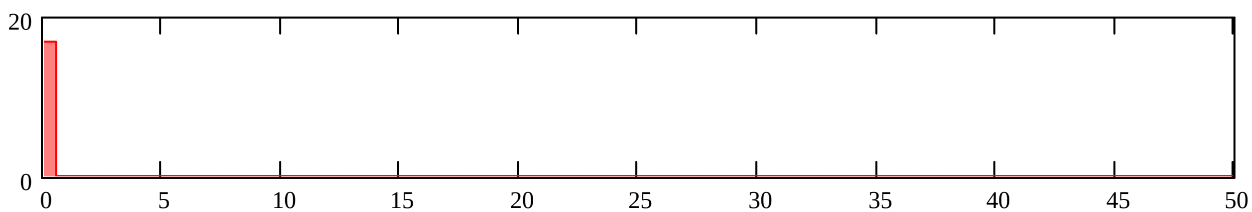
$N := 1024 \qquad m := 1..N$

$x_m := i_{dc}\left(\frac{m}{N}\cdot n_f\right) \qquad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(1)| = 16.888$

**FFT de $i_{dc}$**




$P_o := 3\cdot V_{o\_n\_rms}\cdot I_{o\_rms}\cdot\cos\left(\text{atan}\left(\omega_s\cdot\frac{L_o}{R_o}\right)\right)$

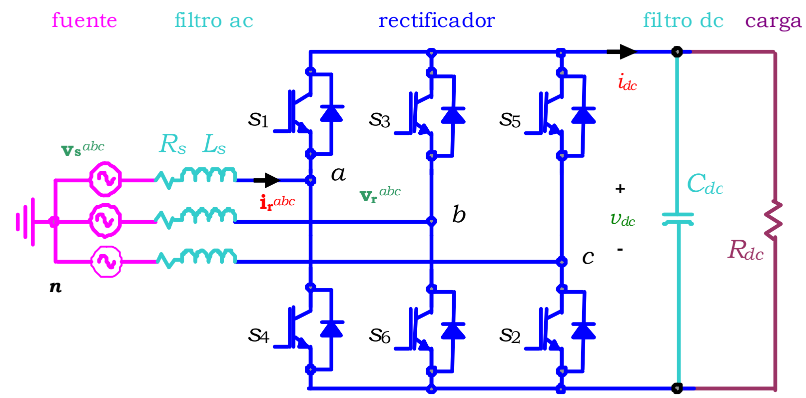
$I_{dc} := \frac{P_o}{V_{dc}} \qquad I_{dc} = 16.916$

**La corriente DC no tiene segunda armónica.**

# Modelo de Rectificador de Voltaje Trifásico



**Problema** Estudiar el modelo del rectificador de voltaje con Modulación SPWM.




$$v_{r\_an}(t) + v_{r\_bn}(t) + v_{r\_cn}(t) = 0$$

$$\begin{pmatrix} v_{r\_ab}(t) \\ v_{r\_bc}(t) \\ 0 \end{pmatrix} = \begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 1 & 1 \end{pmatrix} \cdot \begin{pmatrix} v_{r\_an}(t) \\ v_{r\_bn}(t) \\ v_{r\_cn}(t) \end{pmatrix}$$

$$v_{r\_ab}(t) = s_{ab}(t)\cdot v_{dc}(t) = \left(s_1(t) - s_3(t)\right)\cdot v_{dc}(t)$$

$$v_{r\_bc}(t) = s_{bc}(t)\cdot v_{dc}(t) = \left(s_3(t) - s_5(t)\right)\cdot v_{dc}(t)$$

$$v_{r\_ca}(t) = s_{ca}(t)\cdot v_{dc}(t) = \left(s_5(t) - s_1(t)\right)\cdot v_{dc}(t)$$

Parámetros

$L_s := 30\cdot 10^{-3}$ $\quad R_s := 1$

$C_{dc} := 500\cdot 10^{-6}$ $\quad R_{dc} := 100$

$$\begin{pmatrix} v_{r\_an}(t) \\ v_{r\_bn}(t) \\ v_{r\_cn}(t) \end{pmatrix} = \frac{1}{3}\cdot\begin{pmatrix} 2 & -1 & -1 \\ -1 & 1 & 1 \\ -1 & -2 & 1 \end{pmatrix}\cdot\begin{pmatrix} v_{r\_ab}(t) \\ v_{r\_bc}(t) \\ 0 \end{pmatrix} = \frac{1}{3}\cdot\begin{pmatrix} 2 & -1 & -1 \\ -1 & 1 & 1 \\ -1 & -2 & 1 \end{pmatrix}\cdot\begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 0 \end{pmatrix}\cdot\begin{pmatrix} s_1(t) \\ s_3(t) \\ s_5(t) \end{pmatrix}\cdot v_{dc}(t) = \frac{1}{3}\cdot\begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix}\cdot\begin{pmatrix} s_1(t) \\ s_3(t) \\ s_5(t) \end{pmatrix}\cdot v_{dc}(t) = T_{ln}\cdot s_r(t)\cdot v_{dc}(t)$$

$$v_{s\_a}(t) = R_s\cdot i_{r\_a}(t) + L_s\cdot di_{r\_a}(t) + v_{r\_an}(t)$$

$$v_{s\_b}(t) = R_s\cdot i_{r\_b}(t) + L_s\cdot di_{r\_b}(t) + v_{r\_bn}(t)$$

$$v_{s\_c}(t) = R_s\cdot i_{r\_c}(t) + L_s\cdot di_{r\_c}(t) + v_{r\_cn}(t)$$

$$i_{dc}(t) = C_{dc}\cdot dv_{dc}(t) + \frac{v_{dc}(t)}{R_{dc}}$$

$$v_{dc}(t)\cdot i_{dc}(t) = v_{r\_n}(t)^T\cdot i_r(t)$$

$$v_{r\_n}(t) = T_{ln}\cdot s_r(t)\cdot v_{dc}(t)$$

$$v_{dc}(t)\cdot i_{dc}(t) = \left(T_{ln}\cdot s_r(t)\cdot v_{dc}(t)\right)^T\cdot i_r(t)$$

$$i_{dc}(t) = s_r(t)^T\cdot T_{ln}^{\,T}\cdot i_r(t)$$

$$i_{dc}(t) = s_r(t)^T\cdot T_{ln}\cdot i_r(t)$$

$$v_s(t) = R_s\cdot i_r(t) + L_s\cdot di_r(t) + T_{ln}\cdot s_r(t)\cdot v_{dc}(t)$$

$$s_r(t)^T\cdot T_{ln}\cdot i_r(t) = C_{dc}\cdot dv_{dc}(t) + \frac{v_{dc}(t)}{R_{dc}}$$

$$di_r(t) = \frac{-R_s}{L_s}\cdot i_r(t) - \frac{1}{L_s}\cdot T_{ln}\cdot s_r(t)\cdot v_{dc}(t) + \frac{1}{L_s}\cdot v_s(t)$$

$$dv_{dc}(t) = \frac{-1}{C_{dc}\cdot R_{dc}}\cdot v_{dc}(t) + \frac{1}{C_{dc}}\cdot s_r(t)^T\cdot T_{ln}\cdot i_r(t)$$

$$v_s(t) := \left(\sqrt{2}\cdot 220\cdot\sin(\omega_s\cdot t) \quad \sqrt{2}\cdot 220\cdot\sin\left(\omega_s\cdot t - 2\cdot\frac{\pi}{3}\right) \quad \sqrt{2}\cdot 220\cdot\sin\left(\omega_s\cdot t - 4\cdot\frac{\pi}{3}\right)\right)^T$$

$$s_r(t) := s_i(t)$$

Simulación $\quad t_f := 0.02 \quad n_f := 2048 \quad n := 1 .. n_f \quad t := 0, \frac{t_f}{n_f} .. t_f$

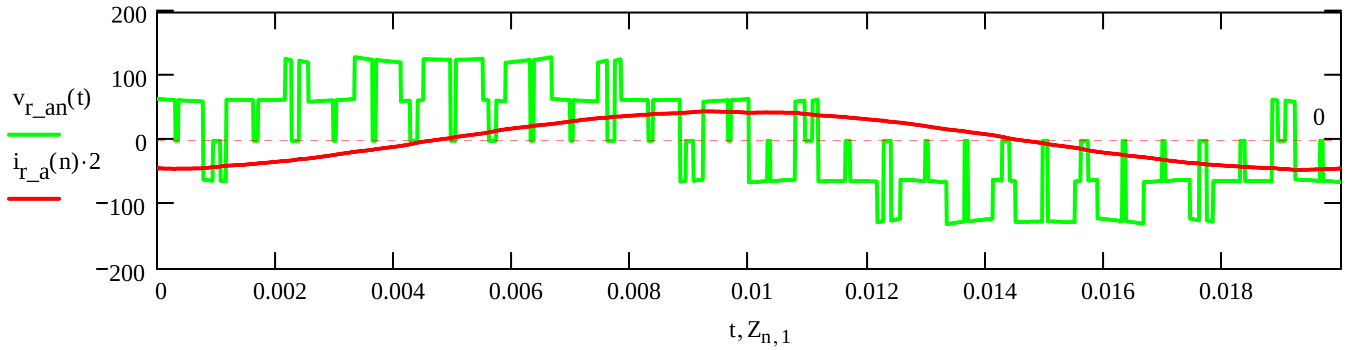
$$D(t,x) := \text{stack}\left(\frac{-R_s}{L_s}\cdot\left(x_1 \quad x_2 \quad x_3\right)^T - \frac{1}{L_s}\cdot T_{ln}\cdot s_r(t)\cdot x_4 + \frac{1}{L_s}\cdot v_s(t), \frac{-1}{C_{dc}\cdot R_{dc}}\cdot x_4 + \frac{1}{C_{dc}}\cdot\left(s_r(t)\right)^T\cdot T_{ln}\cdot\left(x_1 \quad x_2 \quad x_3\right)^T\right)$$

$CI := (-21.463 \quad 8.749 \quad 12.714 \quad 197.244)^T$ $\quad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$ $\qquad CI := \left(Z_{n_f,2} \quad Z_{n_f,3} \quad Z_{n_f,4} \quad Z_{n_f,5}\right)^T$ $\quad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

$v_{dc}(n) := Z_{n,5}$  $v_{r\_an}(t) := \left(T_{ln}\cdot s_r(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_1$  $v_{r\_bn}(t) := \left(T_{ln}\cdot s_r(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_2$  $v_{r\_cn}(t) := \left(T_{ln}\cdot s_r(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_3$



$i_{r\_a}(n) := Z_{n,2}$  $i_{r\_b}(n) := Z_{n,3}$  $i_{r\_c}(n) := Z_{n,4}$  $i_{dc}(n) := \left(s_r\left(n\cdot\frac{t_f}{n_f}\right)\right)^T\cdot\left(T_{ln}\right)^T\cdot\left(i_{r\_a}(n)\;\; i_{r\_b}(n)\;\; i_{r\_c}(n)\right)^T$




$N := 1024$  $m := 1 .. N$

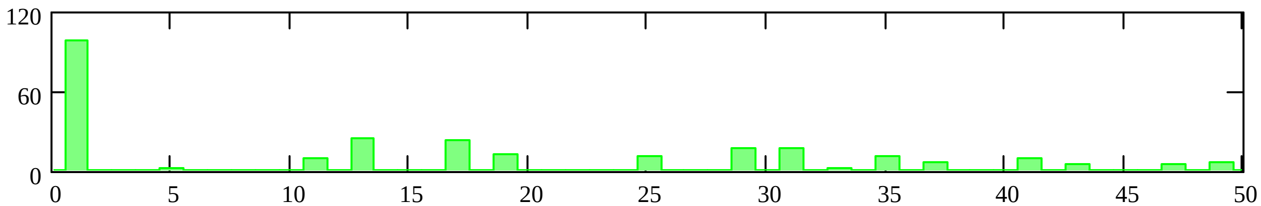
$x_m := v_{r\_an}\left(\frac{m}{N}\cdot t_f\right)$  $xf := FFT(x)$

$xv(m) := if(m = 1, 1, 2)\cdot xf_{m\cdot per}$

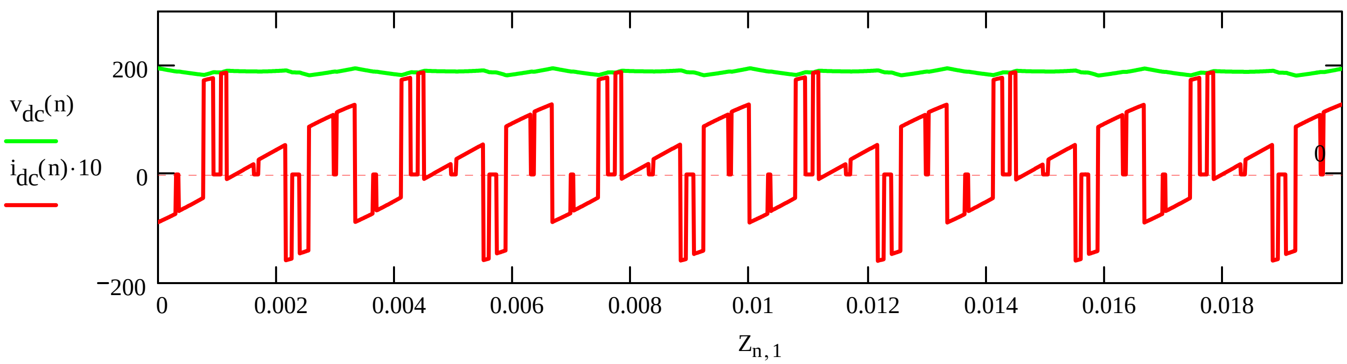
$|xv(2)| = 97.834$

$\frac{1}{2}\cdot M\cdot v_{dc}(1) = 102.624$

**FFT de $v_{r\_an}$**




**La fundamental de voltaje de fase es igual a la moduladora sobre 2.**




$N := 1024$  $m := 1 .. N$

$x_m := i_{dc}\left(\frac{m}{N}\cdot n_f\right)$  $xf := FFT(x)$

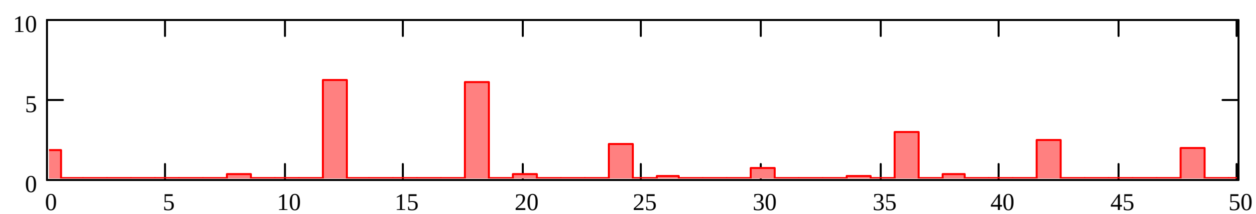
$xv(m) := if(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(1)| = 1.814$  $I_{dc} := |xv(1)|$

$P_o := R_{dc}\cdot I_{dc}^{\,2}$

$P_o = 329.069$

**FFT de $i_{dc}$**




**La corriente DC no tiene segunda armónica. Sólo armónicas de conmutación.**

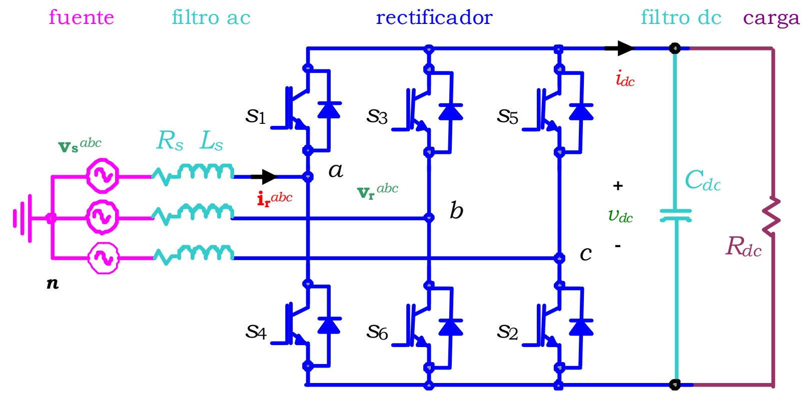
**Problema** Estudiar el modelo promedio del rectificador de voltaje.

$$\begin{pmatrix} v_{r\_an}(t) \\ v_{r\_bn}(t) \\ v_{r\_cn}(t) \end{pmatrix} = m_r(t)\cdot v_{dc}(t)$$

Parámetros

$L_s := 30\cdot 10^{-3}$  $R_s := 1$

$C_{dc} := 500\cdot 10^{-6}$  $R_{dc} := 100$




$$v_{s\_a}(t) = R_s\cdot i_{r\_a}(t) + L_s\cdot di_{r\_a}(t) + v_{r\_an}(t)$$

$$v_{s\_b}(t) = R_s\cdot i_{r\_b}(t) + L_s\cdot di_{r\_b}(t) + v_{r\_bn}(t)$$

$$v_{s\_c}(t) = R_s\cdot i_{r\_c}(t) + L_s\cdot di_{r\_c}(t) + v_{r\_cn}(t)$$

$$i_{dc}(t) = C_{dc}\cdot dv_{dc}(t) + \frac{v_{dc}(t)}{R_{dc}}$$

$$v_{dc}(t)\cdot i_{dc}(t) = v_{r\_n}(t)^T\cdot i_r(t)$$

$$v_{r\_n}(t) = m_r(t)\cdot v_{dc}(t)$$

$$v_{dc}(t)\cdot i_{dc}(t) = \left(m_r(t)\cdot v_{dc}(t)\right)^T\cdot i_r(t)$$

$$i_{dc}(t) = m_r(t)^T\cdot i_r(t)$$

$$i_{dc}(t) = m_r(t)^T\cdot i_r(t)$$

$$v_s(t) = R_s\cdot i_r(t) + L_s\cdot di_r(t) + m_r(t)\cdot v_{dc}(t)$$

$$m_r(t)^T\cdot i_r(t) = C_{dc}\cdot dv_{dc}(t) + \frac{v_{dc}(t)}{R_{dc}}$$

$$di_r(t) = \frac{-R_s}{L_s}\cdot i_r(t) - \frac{1}{L_s}\cdot m_r(t)\cdot v_{dc}(t) + \frac{1}{L_s}\cdot v_s(t)$$

$$dv_{dc}(t) = \frac{-1}{C_{dc}\cdot R_{dc}}\cdot v_{dc}(t) + \frac{1}{C_{dc}}\cdot m_r(t)^T\cdot i_r(t)$$

$$v_s(t) := \left(\sqrt{2}\cdot 220\cdot \sin(\omega_s\cdot t)\quad \sqrt{2}\cdot 220\cdot \sin\left(\omega_s\cdot t - 2\cdot\frac{\pi}{3}\right)\quad \sqrt{2}\cdot 220\cdot \sin\left(\omega_s\cdot t - 4\cdot\frac{\pi}{3}\right)\right)^T$$

Simulación $t_f := 0.02$  $n_f := 2048$  $n := 1..n_f$  $t := 0, \frac{t_f}{n_f} .. t_f$

$$m_r(t) := m_i(t)$$

$$D(t,x) := \text{stack}\left(\frac{-R_s}{L_s}\cdot\left(x_1\ x_2\ x_3\right)^T - \frac{1}{L_s}\cdot m_r(t)\cdot x_4 + \frac{1}{L_s}\cdot v_s(t), \frac{-1}{C_{dc}\cdot R_{dc}}\cdot x_4 + \frac{1}{C_{dc}}\cdot m_r(t)^T\cdot\left(x_1\ x_2\ x_3\right)^T\right)$$

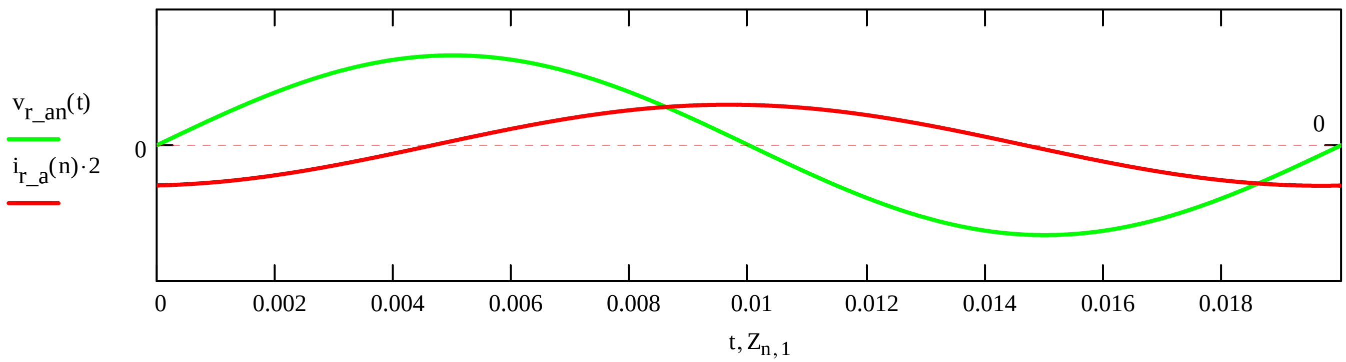
$CI := (-22.073\ \ 9.004\ \ 13.069\ \ 191.267)^T$ $Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

$CI := \left(Z_{n_f,2}\ \ Z_{n_f,3}\ \ Z_{n_f,4}\ \ Z_{n_f,5}\right)^T$ $Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

$v_{dc}(n) := Z_{n,5}$ $\quad v_{r\_an}(t) := \left(m_r(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_1$ $\quad v_{r\_bn}(t) := \left(m_r(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_2$ $\quad v_{r\_cn}(t) := \left(m_r(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_3$



$i_{r\_a}(n) := Z_{n,2}$ $\quad i_{r\_b}(n) := Z_{n,3}$ $\quad i_{r\_c}(n) := Z_{n,4}$ $\quad i_{dc}(n) := \left(m_r\left(n\cdot\frac{t_f}{n_f}\right)\right)\cdot\left(i_{r\_a}(n)\;\; i_{r\_b}(n)\;\; i_{r\_c}(n)\right)^T$




$N := 1024 \qquad m := 1 .. N$

$x_m := v_{r\_an}\left(\frac{m}{N}\cdot t_f\right) \qquad xf := FFT(x)$

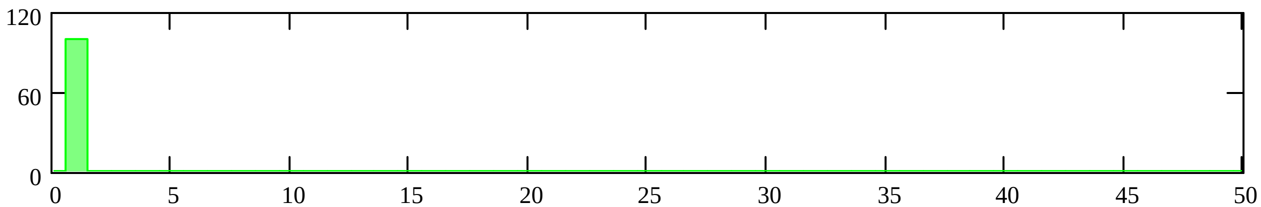
$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

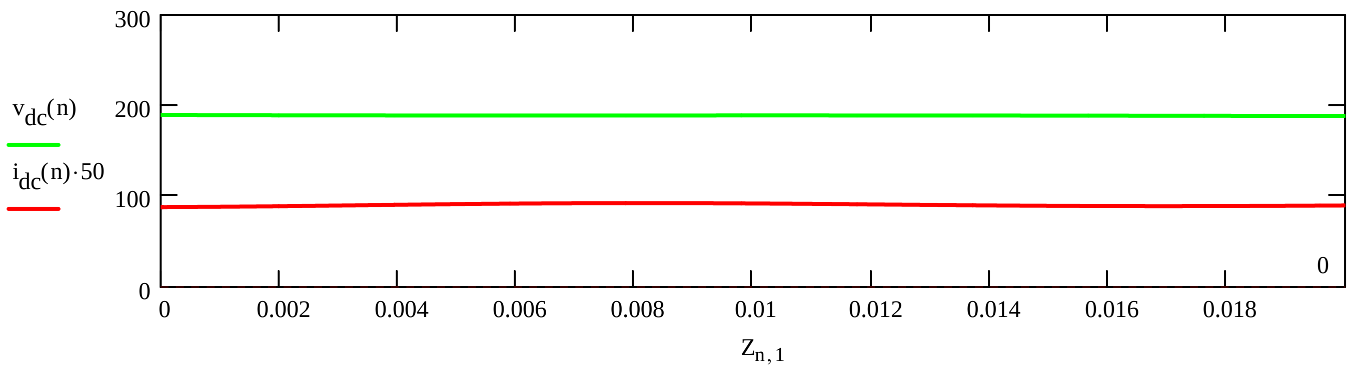
$|xv(2)| = 99.254$

$\frac{1}{2}\cdot M\cdot v_{dc}(1) = 99.554$

**La fundamental de voltaje de fase es igual a la moduladora sobre 2.**

**FFT de $v_{r\_an}$**




$N := 1024 \qquad m := 1 .. N$

$x_m := i_{dc}\left(\frac{m}{N}\cdot n_f\right) \qquad xf := FFT(x)$

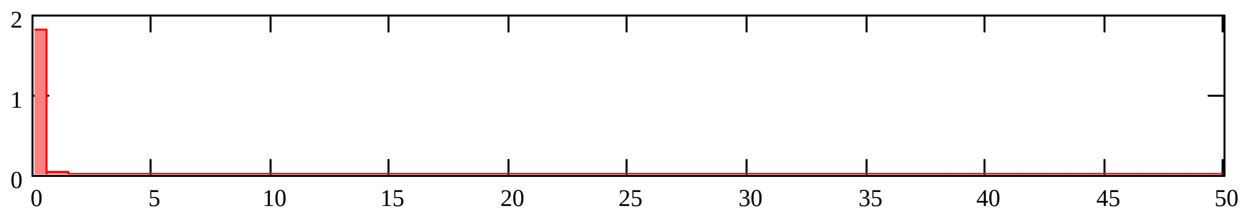
$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(1)| = 1.808 \qquad I_{dc} := |xv(1)|$

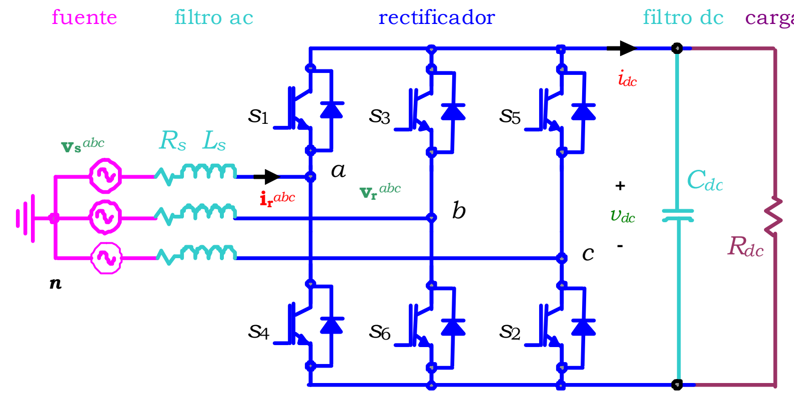
$P_o := R_{dc}\cdot I_{dc}^{\,2}$

$P_o = 327.065$

**FFT de $i_{dc}$**



**Problema** Estudiar el modelo promedio en dq0 del rectificador de voltaje.




$$v_{rdq\_n}(t) = m_{rdq}(t)\cdot v_{dc}(t)$$

$$i_{dc}(t) = m_{rdq}(t)^T\cdot i_{rdq}(t)$$

$$v_{sdq}(t) = R_s\cdot i_{rdq}(t) + L_s\cdot\left(di_{rdq}(t) + W\cdot i_{rdq}(t)\right) + m_{rdq}(t)\cdot v_{dc}(t)$$

$$m_{rdq}(t)^T\cdot i_{rdq}(t) = C_{dc}\cdot dv_{dc}(t) + \frac{v_{dc}(t)}{R_{dc}}$$

$$di_{rdq}(t) = -W\cdot i_{rdq}(t) + \frac{-R_s}{L_s}\cdot i_{rdq}(t) - \frac{1}{L_s}\cdot m_{rdq}(t)\cdot v_{dc}(t) + \frac{1}{L_s}\cdot v_{sdq}(t)$$

$$dv_{dc}(t) = \frac{-1}{C_{dc}\cdot R_{dc}}\cdot v_{dc}(t) + \frac{1}{C_{dc}}\cdot m_{rdq}(t)^T\cdot i_{rdq}(t)$$

**Parámetros**

$$L_s := 30\cdot 10^{-3} \qquad R_s := 1$$

$$C_{dc} := 500\cdot 10^{-6} \qquad R_{dc} := 100 \qquad W := \begin{pmatrix} 0 & -\omega_s \\ \omega_s & 0 \end{pmatrix}$$

$$v_{sdq}(t) := \left(\sqrt{3}\cdot 220 \quad 0\right)^T$$

$$m_{rdq}(t) := \sqrt{\frac{2}{3}}\cdot\begin{pmatrix} \sin(\omega_s\cdot t) & \sin\left(\omega_s\cdot t - 2\cdot\frac{\pi}{3}\right) & \sin\left(\omega_s\cdot t - 4\cdot\frac{\pi}{3}\right) \\ \cos(\omega_s\cdot t) & \cos\left(\omega_s\cdot t - 2\cdot\frac{\pi}{3}\right) & \cos\left(\omega_s\cdot t - 4\cdot\frac{\pi}{3}\right) \end{pmatrix}\cdot m_r(t)$$

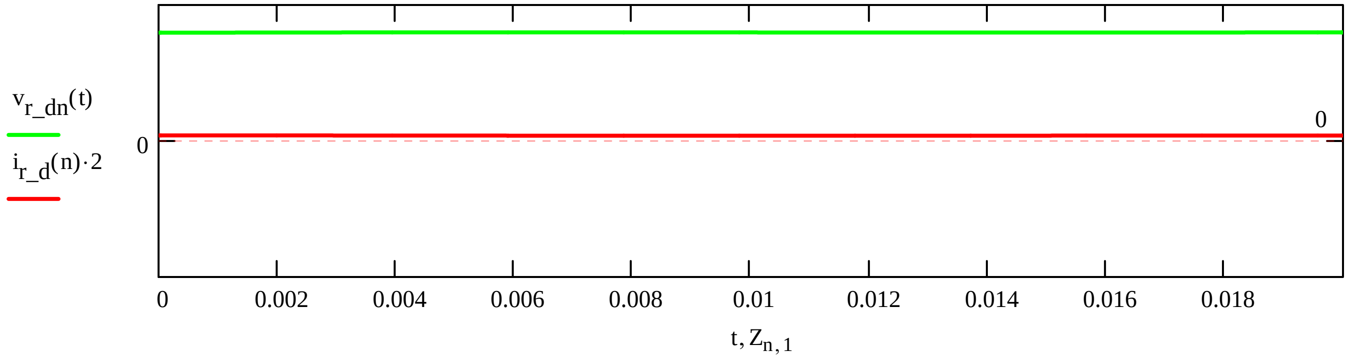
**Simulación** $t_f := 0.02 \qquad n_f := 2048 \qquad n := 1..n_f \qquad t := 0, \frac{t_f}{n_f}..t_f$

$$D(t,x) := \text{stack}\left(-W\cdot(x_1 \quad x_2)^T + \frac{-R_s}{L_s}\cdot(x_1 \quad x_2)^T - \frac{1}{L_s}\cdot m_{rdq}(t)\cdot x_3 + \frac{1}{L_s}\cdot v_{sdq}(t), \frac{-1}{C_{dc}\cdot R_{dc}}\cdot x_3 + \frac{1}{C_{dc}}\cdot m_{rdq}(t)^T\cdot(x_1 \quad x_2)^T\right)$$

$$CI := (2.948 \quad -27.293 \quad 184.503)^T \qquad Z := \text{rkfixed}(CI, 0, t_f, n_f, D) \qquad CI := \left(Z_{n_f,2} \quad Z_{n_f,3} \quad Z_{n_f,4}\right)^T \qquad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$$

$v_{dc}(n) := Z_{n,4}$ $\quad v_{r\_dn}(t) := \left(m_{rdq}(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_1$ $\quad v_{r\_qn}(t) := \left(m_{rdq}(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_2$

$i_{r\_d}(n) := Z_{n,2}$ $\quad i_{r\_q}(n) := Z_{n,3}$ $\quad i_{dc}(n) := \left(m_{rdq}\left(n\cdot\frac{t_f}{n_f}\right)\right)^T\cdot\left(i_{r\_d}(n)\ \ i_{r\_q}(n)\right)^T$




$N := 1024$ $\qquad m := 1..N$

$x_m := v_{r\_dn}\left(\frac{m}{N}\cdot t_f\right)$ $\qquad xf := FFT(x)$

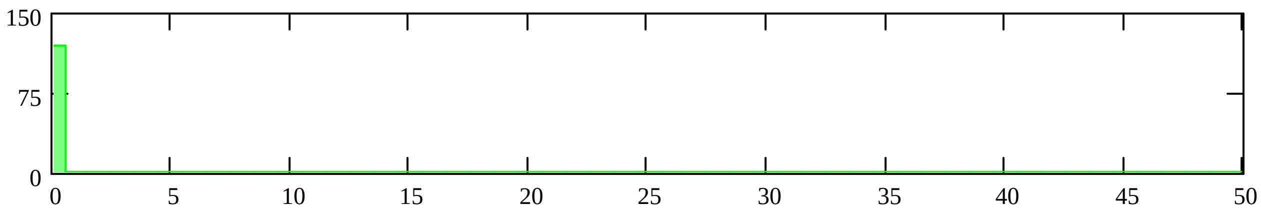
$xv(m) := if(m = 1, 1, 2)\cdot xf_{m\cdot per}$

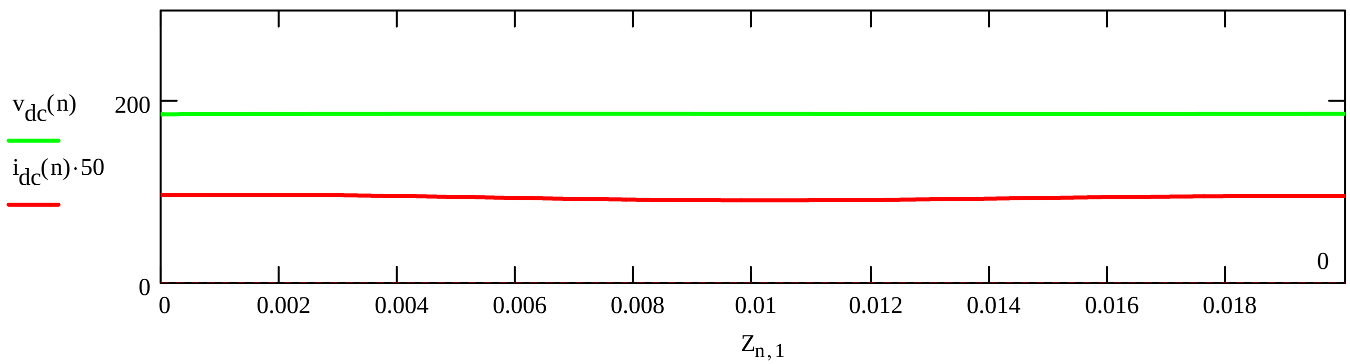
$\sqrt{\frac{2}{3}}\cdot\sqrt{v_{r\_dn}(0.01)^2 + v_{r\_qn}(0.01)^2} = 97.697$

$\sqrt{\frac{2}{3}}\cdot\left|m_{rdq}(0.01)\right|\cdot v_{dc}(1) = 97.44$

$\frac{1}{2}\cdot M\cdot v_{dc}(1) = 97.44$

**FFT de $v_{r\_dn}$**




$N := 1024$ $\qquad m := 1..N$

$x_m := i_{dc}\left(\frac{m}{N}\cdot n_f\right)$ $\qquad xf := FFT(x)$

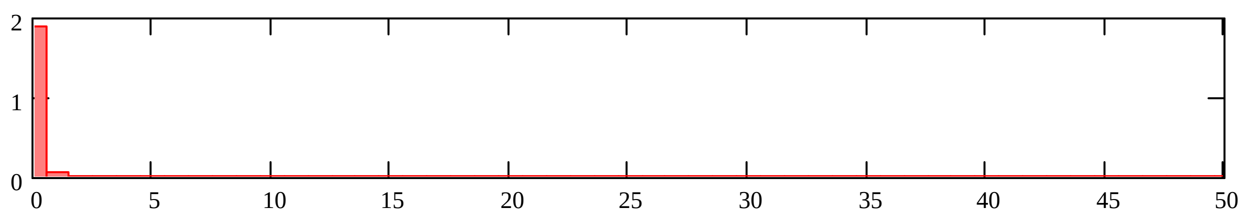
$xv(m) := if(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(1)| = 1.876$ $\qquad I_{dc} := |xv(1)|$

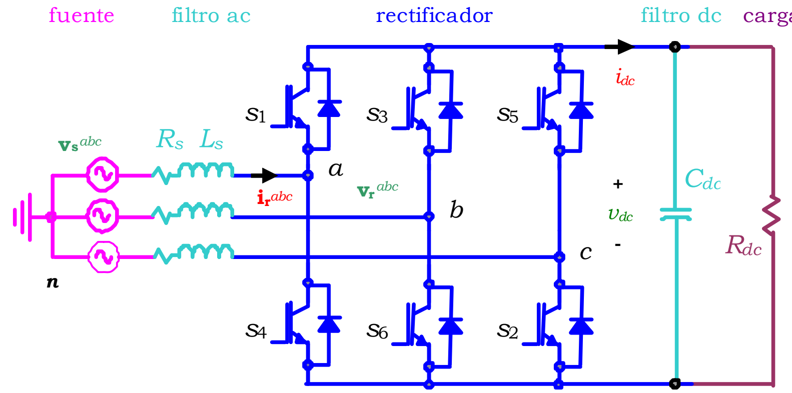
$P_o := R_{dc}\cdot I_{dc}^2$

$P_o = 352.03$

**FFT de $i_{dc}$**



**Problema** Encontrar un punto de operación




$\phi_0 := -30\cdot\frac{\pi}{180}$ $\quad P_{dc\_0} := 5000$ $\quad \begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} := \begin{pmatrix} \sqrt{3}\cdot 220 \\ 0 \end{pmatrix}$

c.i. para Given/Find que deben ser igual en número al número de incógnitas

$\begin{pmatrix} I_{rd} \\ I_{rq} \end{pmatrix} := \begin{pmatrix} 10 \\ 0 \end{pmatrix}$ $\quad \begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix} := \begin{pmatrix} 0.5 \\ 0. \end{pmatrix}$ $\quad V_{dc} := 500$

Given

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W\cdot\begin{pmatrix} I_{rd} \\ I_{rq} \end{pmatrix} + \frac{-R_s}{L_s}\cdot\begin{pmatrix} I_{rd} \\ I_{rq} \end{pmatrix} - \frac{1}{L_s}\cdot\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}\cdot V_{dc} + \frac{1}{L_s}\cdot\begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix}$$

$$\phi_0 = \text{atan}\left(\frac{I_{rq}}{I_{rd}}\right)$$

$$0 = \frac{-1}{C_{dc}\cdot R_{dc}}\cdot V_{dc} + \frac{1}{C_{dc}}\cdot\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}^T\cdot\begin{pmatrix} I_{rd} \\ I_{rq} \end{pmatrix}$$

$$P_{dc\_0} = \frac{V_{dc}^2}{R_{dc}}$$

$$\begin{pmatrix} I_{rd} & I_{rq} & V_{dc} & M_{rd} & M_{rq} \end{pmatrix} := \text{Find}(I_{rd}, I_{rq}, V_{dc}, M_{rd}, M_{rq})^T$$

$$\begin{pmatrix} I_{rd} & I_{rq} & V_{dc} & M_{rd} & M_{rq} \end{pmatrix} = (13.787 \quad -7.96 \quad 707.107 \quad 0.413 \quad -0.173)$$

$m_{rdq}(t) := \begin{pmatrix} M_{rd} & M_{rq} \end{pmatrix}^T$ $\quad v_{sdq}(t) := \begin{pmatrix} V_{sd} & 0 \end{pmatrix}^T$

$$T_{abc\_dq0}(t) := \sqrt{\frac{2}{3}}\cdot\begin{pmatrix} \sin(\omega_s\cdot t) & \sin\left(\omega_s\cdot t - 2\cdot\frac{\pi}{3}\right) & \sin\left(\omega_s\cdot t - 4\cdot\frac{\pi}{3}\right) \\ \cos(\omega_s\cdot t) & \cos\left(\omega_s\cdot t - 2\cdot\frac{\pi}{3}\right) & \cos\left(\omega_s\cdot t - 4\cdot\frac{\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

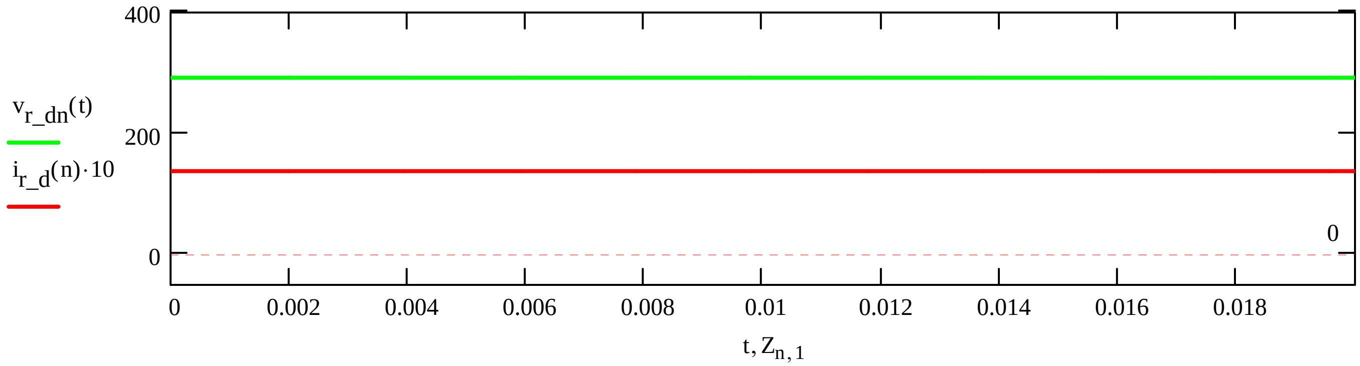
**Simulación** $\quad t_f := 0.02 \quad n_f := 2048 \quad n := 1 .. n_f \quad t := 0, \frac{t_f}{n_f} .. t_f$

$$D(t,x) := \text{stack}\left[-W\cdot(x_1 \;\; x_2)^T + \frac{-R_s}{L_s}\cdot(x_1 \;\; x_2)^T - \frac{1}{L_s}\cdot m_{rdq}(t)\cdot x_3 + \frac{1}{L_s}\cdot v_{sdq}(t), \frac{-1}{C_{dc}\cdot R_{dc}}\cdot x_3 + \frac{1}{C_{dc}}\cdot\left((m_{rdq}(t))^T\cdot((x_1 \;\; x_2))^T\right)\right]$$

$CI := \begin{pmatrix} I_{rd} & I_{rq} & V_{dc} \end{pmatrix}^T$ $\quad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$ $\quad CI := \begin{pmatrix} Z_{n_f,2} & Z_{n_f,3} & Z_{n_f,4} \end{pmatrix}^T$ $\quad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

$v_{dc}(n) := Z_{n,4}$ $\quad v_{r\_dn}(t) := \left(m_{rdq}(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_1$ $\quad v_{r\_qn}(t) := \left(m_{rdq}(t)\cdot v_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_2$

$i_{r\_d}(n) := Z_{n,2}$ $\quad i_{r\_q}(n) := Z_{n,3}$ $\quad i_{dc}(n) := \left(m_{rdq}\left(n\cdot\frac{t_f}{n_f}\right)\right)^T\cdot\left(i_{r\_d}(n)\ \ i_{r\_q}(n)\right)^T$




$N := 1024$ $\quad m := 1..N$

$x_m := v_{r\_dn}\left(\frac{m}{N}\cdot t_f\right)$ $\quad xf := FFT(x)$

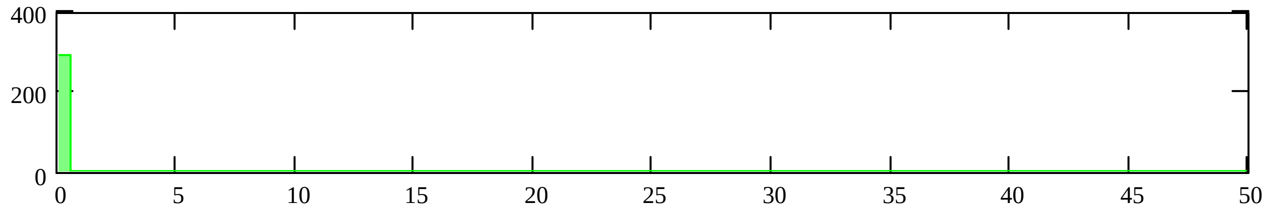
$xv(m) := \mathrm{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

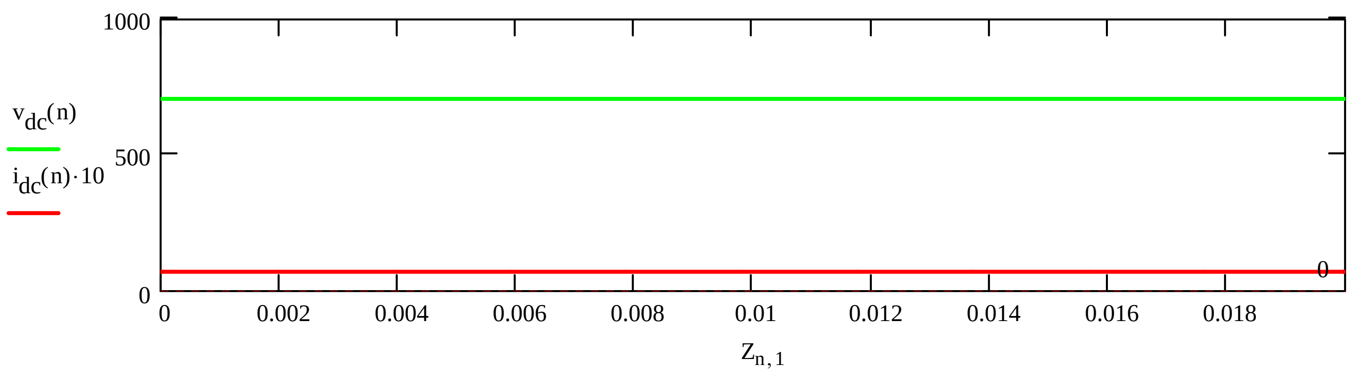
$$\sqrt{\frac{2}{3}}\cdot\sqrt{v_{r\_dn}(0.01)^2 + v_{r\_qn}(0.01)^2} = 258.568$$

$$\sqrt{\frac{2}{3}}\cdot\left|m_{rdq}(0.01)\right|\cdot v_{dc}(1) = 258.568$$

$$\mathrm{atan}\left(\frac{i_{r\_q}(1)}{i_{r\_d}(1)}\right)\cdot\frac{180}{\pi} = -30$$

**FFT de $v_{r\_dn}$**




$N := 1024$ $\quad m := 1..N$

$x_m := i_{dc}\left(\frac{m}{N}\cdot n_f\right)$ $\quad xf := FFT(x)$

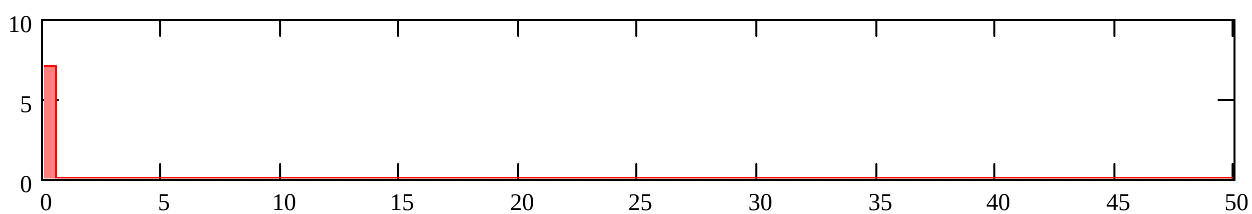
$xv(m) := \mathrm{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(1)| = 7.071$ $\quad I_{dc} := |xv(1)|$

$P_o := R_{dc}\cdot I_{dc}^{\ 2}$

$P_o = 5\times 10^3$

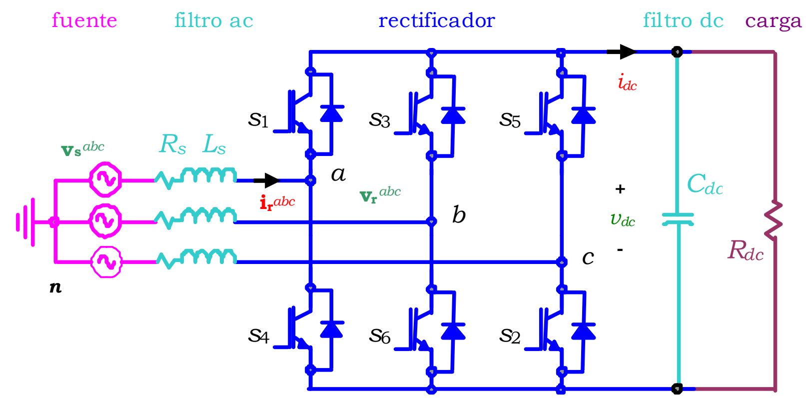
**FFT de $i_{dc}$**



# Punto de operación del Rectificador de Voltaje Trifásico en abc



**Problema** Simular el punto de operación.




$$\frac{d}{dt} i_r(t) = \frac{-R_s}{L_s} \cdot i_r(t) - \frac{1}{L_s} \cdot T_{ln} \cdot s_r(t) \cdot v_{dc}(t) + \frac{1}{L_s} \cdot v_s(t)$$

$$\frac{d}{dt} v_{dc}(t) = \frac{-1}{C_{dc} \cdot R_{dc}} \cdot v_{dc}(t) + \frac{1}{C_{dc}} \cdot s_r(t)^T \cdot T_{ln} \cdot i_r(t)$$

$$m_r(t) := T_{abc\_dq0}(t)^T \cdot \begin{pmatrix} M_{rd} \\ M_{rq} \\ 0 \end{pmatrix}$$

$m_a(t) := 2 \cdot m_r(t)_1$ $\quad m_b(t) := 2 \cdot m_r(t)_2$ $\quad m_c(t) := 2 \cdot m_r(t)_3$

$$M := \sqrt{\frac{2}{3}} \cdot \sqrt{m_a(0)^2 + m_b(0)^2 + m_c(0)^2} \qquad f_M := \operatorname{atan}\left(\frac{M_{rq}}{M_{rd}}\right)$$

$$M = 0.731 \qquad f_M \cdot \frac{180}{\pi} = -22.655$$

$$tri(t) := \frac{2}{\pi} \cdot \operatorname{asin}\left(\sin\left(f_{n\_tr} \cdot \omega_s \cdot t + f_M \cdot f_{n\_tr} - \pi\right)\right)$$

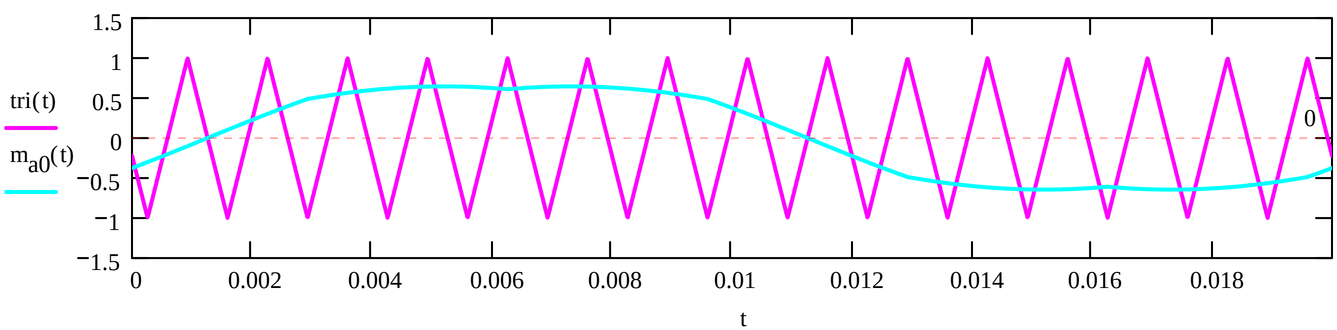
$$sup(t) := \text{if}\left(m_a(t) > m_b(t), \text{if}\left(m_a(t) > m_c(t), m_a(t), m_c(t)\right), \text{if}\left(m_b(t) > m_c(t), m_b(t), m_c(t)\right)\right)$$

$$inf(t) := \text{if}\left(m_a(t) < m_b(t), \text{if}\left(m_a(t) < m_c(t), m_a(t), m_c(t)\right), \text{if}\left(m_b(t) < m_c(t), m_b(t), m_c(t)\right)\right) \qquad seq_0(t) := (sup(t) + inf(t)) \cdot \frac{1}{3}$$

$m_{a0}(t) := m_a(t) - seq_0(t)$ $\quad m_{b0}(t) := m_b(t) - seq_0(t)$ $\quad m_{c0}(t) := m_c(t) - seq_0(t)$

$s_1(t) := \text{if}\left(m_{a0}(t) > tri(t), 1, 0\right)$ $\quad s_3(t) := \text{if}\left(m_{b0}(t) > tri(t), 1, 0\right)$ $\quad s_5(t) := \text{if}\left(m_{c0}(t) > tri(t), 1, 0\right)$

$$s_r(t) := \begin{pmatrix} s_1(t) \\ s_3(t) \\ s_5(t) \end{pmatrix} \qquad v_s(t) := T_{abc\_dq0}(t)^T \cdot \begin{pmatrix} V_{sd} \\ V_{sq} \\ 0 \end{pmatrix}$$



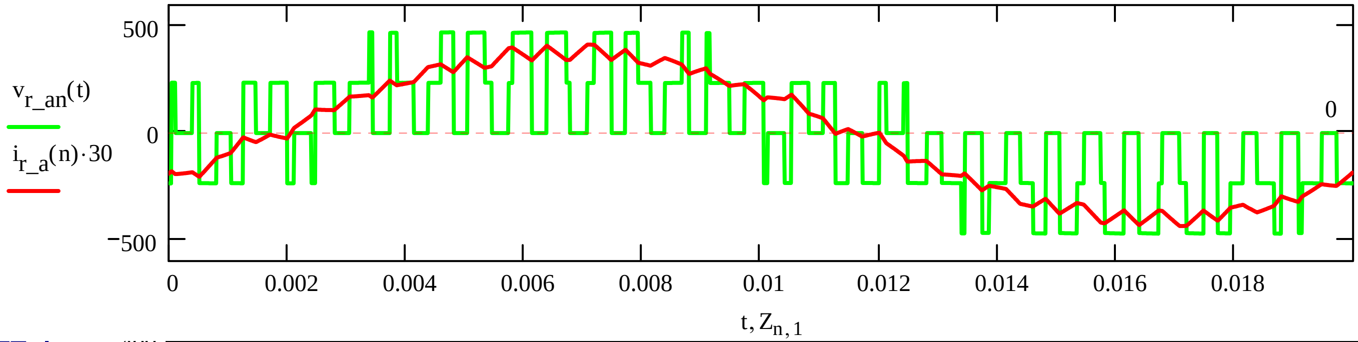

**Simulación** $\quad t_f := 0.02 \quad n_f := 2048 \quad n := 1..n_f \quad t := 0, \frac{t_f}{n_f} .. t_f$

$$D(t,x) := \text{stack}\left(\frac{-R_s}{L_s} \cdot \left(x_1 \; x_2 \; x_3\right)^T - \frac{1}{L_s} \cdot T_{ln} \cdot s_r(t) \cdot x_4 + \frac{1}{L_s} \cdot v_s(t), \frac{-1}{C_{dc} \cdot R_{dc}} \cdot x_4 + \frac{1}{C_{dc}} \cdot \left(s_r(t)\right)^T \cdot T_{ln} \cdot \left(x_1 \; x_2 \; x_3\right)^T\right)$$

$CI := \text{stack}\left(T_{abc\_dq0}(0)^T \cdot \left(I_{rd}\ \ I_{rq}\ \ 0\right)^T, V_{dc}\right)$ $\quad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$ $\qquad CI := \left(Z_{n_f,2}\ \ Z_{n_f,3}\ \ Z_{n_f,4}\ \ Z_{n_f,5}\right)^T$ $\quad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

$v_{dc}(n) := Z_{n,5}$ $\quad v_{r\_an}(t) := \left(T_{ln} \cdot s_r(t) \cdot v_{dc}\left(t \cdot \frac{n_f}{t_f}\right)\right)_1$ $\quad v_{r\_bn}(t) := \left(T_{ln} \cdot s_r(t) \cdot v_{dc}\left(t \cdot \frac{n_f}{t_f}\right)\right)_2$ $\quad v_{r\_cn}(t) := \left(T_{ln} \cdot s_r(t) \cdot v_{dc}\left(t \cdot \frac{n_f}{t_f}\right)\right)_3$

$i_{r\_a}(n) := Z_{n,2}$ $\quad i_{r\_b}(n) := Z_{n,3}$ $\quad i_{r\_c}(n) := Z_{n,4}$ $\quad i_{dc}(n) := \left(s_r\left(n \cdot \frac{t_f}{n_f}\right)\right)^T \cdot \left(T_{ln}\right)^T \cdot \left(i_{r\_a}(n)\ \ i_{r\_b}(n)\ \ i_{r\_c}(n)\right)^T$




$N := 1024 \qquad m := 1..N$

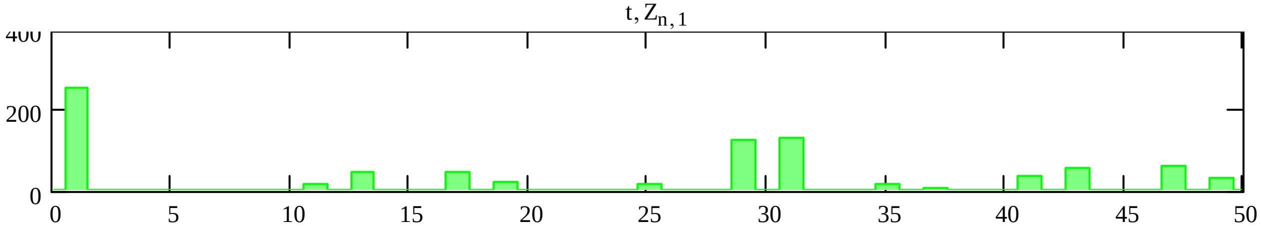
$x_m := v_{r\_an}\left(\frac{m}{N} \cdot t_f\right) \qquad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2) \cdot xf_{m \cdot per}$

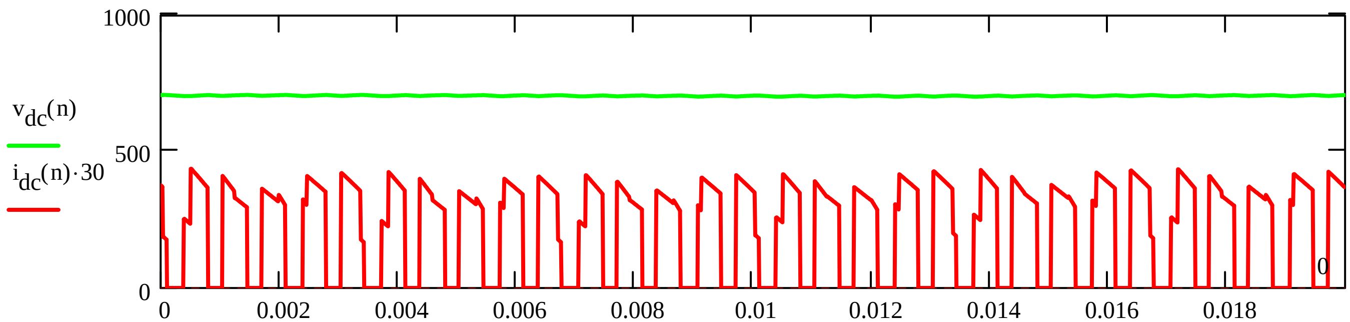
$|xv(2)| = 257.318$

$\frac{1}{2} \cdot M \cdot v_{dc}(1) = 258.83$

**FFT de $v_{r\_an}$**




**La fundamental de voltaje de fase es igual a la moduladora sobre 2.**




$N := 1024 \qquad m := 1..N$

$x_m := i_{dc}\left(\frac{m}{N} \cdot n_f\right) \qquad xf := FFT(x)$

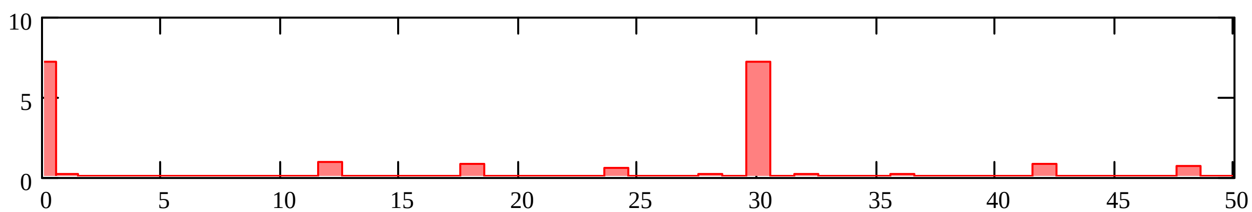
$xv(m) := \text{if}(m = 1, 1, 2) \cdot xf_{m \cdot per}$

$|xv(1)| = 7.126 \qquad I_{dc} := |xv(1)|$

$P_o := R_{dc} \cdot I_{dc}^2$

$P_o = 5.078 \times 10^3$

**FFT de $i_{dc}$**

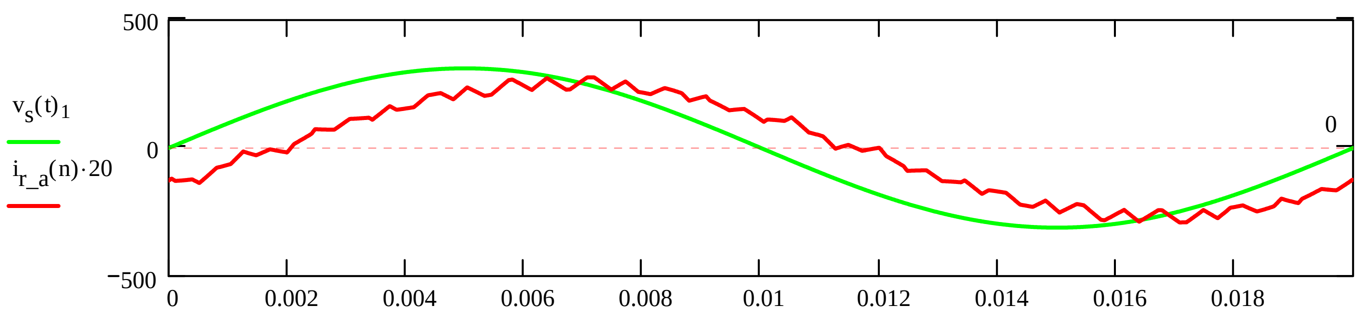


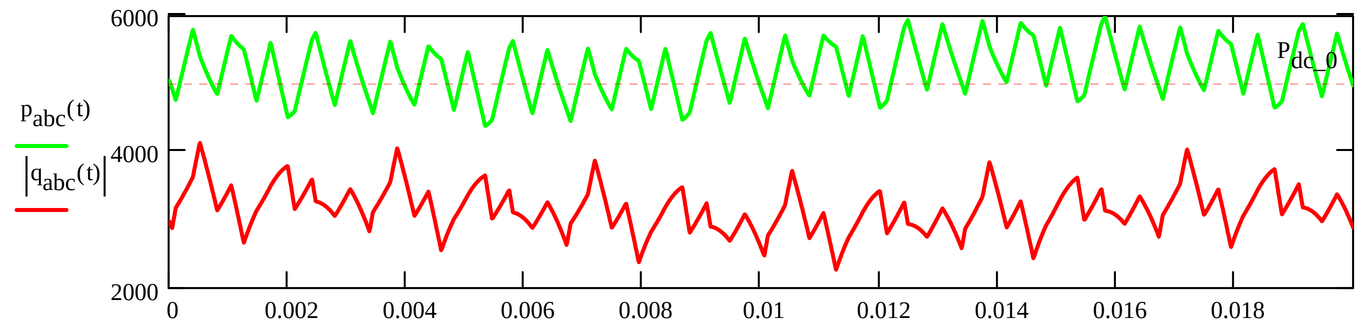
$v_{abc}(t) := v_s(t)$ $\quad i_{abc}(t) := \left( i_{r\_a}\left(t\cdot\frac{n_f}{t_f}\right) \;\; i_{r\_b}\left(t\cdot\frac{n_f}{t_f}\right) \;\; i_{r\_c}\left(t\cdot\frac{n_f}{t_f}\right) \right)^T$ $\quad p_{abc}(t) := v_{abc}(t)^T \cdot i_{abc}(t)$ $\quad q_{abc}(t) := v_{abc}(t) \times i_{abc}(t)$

$$s_{abc}(t) := \sqrt{\left(\left|v_{abc}(t)\right|\right)^2 \cdot \left(\left|i_{abc}(t)\right|\right)^2}$$

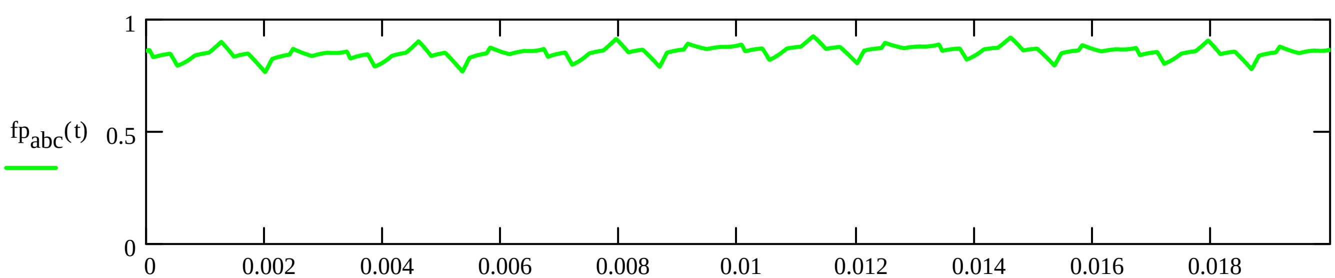
$$fp_{abc}(t) := \frac{p_{abc}(t)}{s_{abc}(t)}$$

$$\phi(t) := \operatorname{atan}\left[\frac{\left(T_{abc\_dq0}(t)\cdot i_{abc}(t)\right)_2}{\left(T_{abc\_dq0}(t)\cdot i_{abc}(t)\right)_1}\right]$$

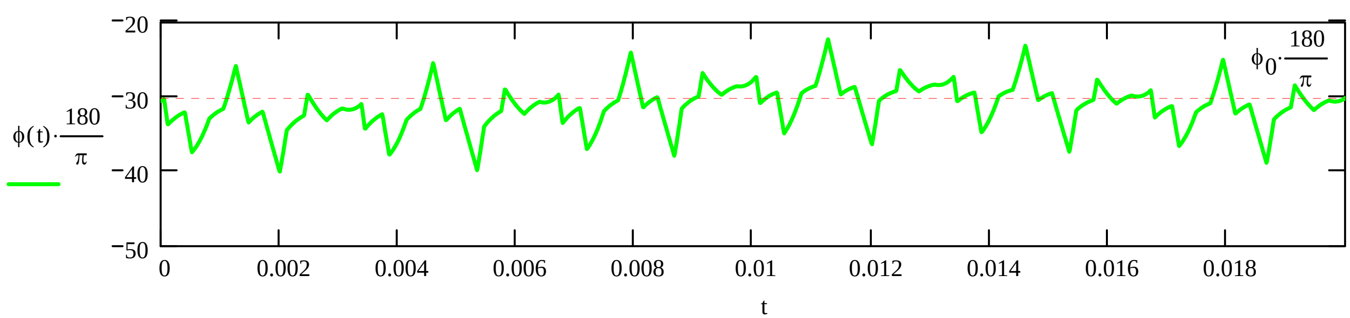


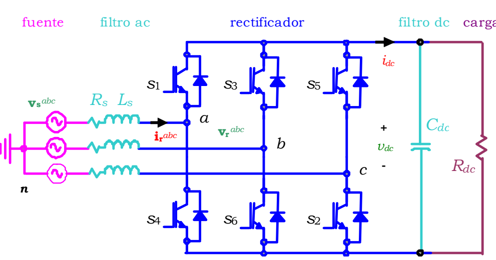




El sistema todavía no está en S.S.



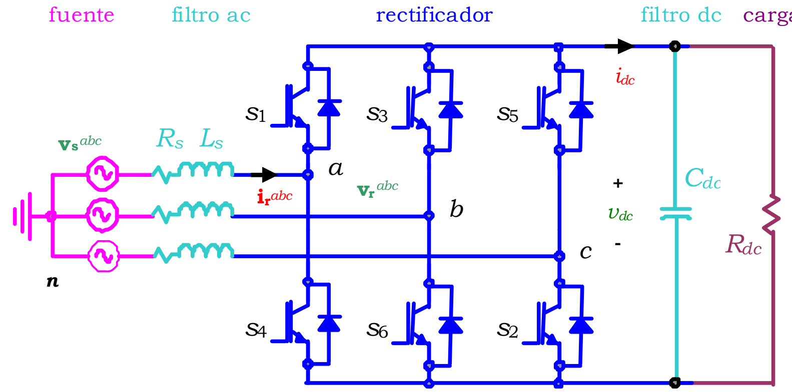

¿ Qué rangos puede alcanzar el sistema ?... **La Región de Operación** entrega esta respuesta.



**Problema** Estudiar el modelo promedio en dq0 del rectificador de voltaje.

$t := 0$




$$m_{r\_abc}(M, f_M) := \frac{1}{2} \cdot \begin{pmatrix} M \cdot \sin\left(\omega_s \cdot t + f_M - \frac{0 \cdot \pi}{3}\right) \\ M \cdot \sin\left(\omega_s \cdot t + f_M - \frac{2 \cdot \pi}{3}\right) \\ M \cdot \sin\left(\omega_s \cdot t + f_M - \frac{4 \cdot \pi}{3}\right) \end{pmatrix}$$

$$m_{r\_dq0}(M, f_M) := T_{abc\_dq0}(t) \cdot m_{r\_abc}(M, f_M)$$

$$X_a(M, f_M) := m_{r\_abc}(M, f_M)_1$$

$$Y_b(M, f_M) := m_{r\_abc}(M, f_M)_2$$

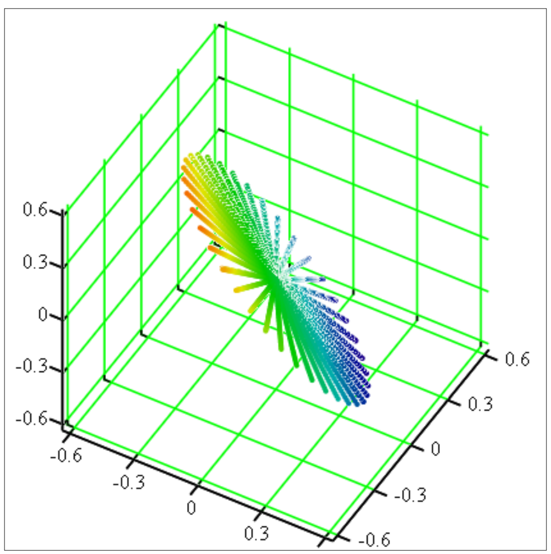
$$Z_c(M, f_M) := m_{r\_abc}(M, f_M)_3$$

$$X_d(M, f_M) := m_{r\_dq0}(M, f_M)_1$$

$$Y_q(M, f_M) := m_{r\_dq0}(M, f_M)_2$$

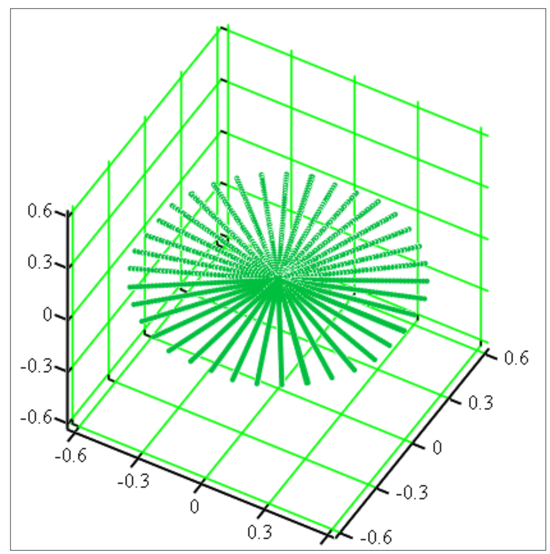
$$Z_0(M, f_M) := m_{r\_dq0}(M, f_M)_3$$

Las señales en abc en función de M y $f_M$.




$(X_a, Y_b, Z_c)$

Las señales en dq0 en función de M y $f_M$.

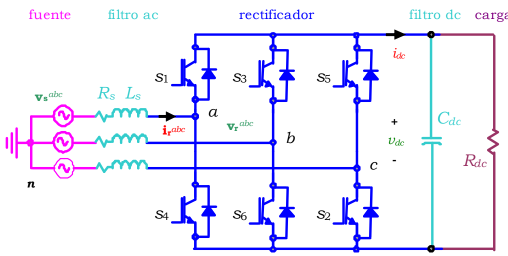



$(X_d, Y_q, Z_0)$

c.i. para Given/Find que deben ser igual en número al número de incógnitas



$\begin{pmatrix} I_{rd} \\ I_{rq} \end{pmatrix} := \begin{pmatrix} 10 \\ 0 \end{pmatrix}$ $\quad \begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix} := \begin{pmatrix} 0.5 \\ 0. \end{pmatrix}$ $\quad V_{dc} := 500$ $\quad \begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} := \begin{pmatrix} \sqrt{3}\cdot 220 \\ 0 \end{pmatrix}$ $\quad Max := \frac{1}{2}\cdot\sqrt{\frac{3}{2}}$




Given

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W\cdot\begin{pmatrix} I_{rd} \\ I_{rq} \end{pmatrix} + \frac{-R_s}{L_s}\cdot\begin{pmatrix} I_{rd} \\ I_{rq} \end{pmatrix} - \frac{1}{L_s}\cdot\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}\cdot V_{dc} + \frac{1}{L_s}\cdot\begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix}$$

$$0 = \frac{-1}{C_{dc}\cdot R_{dc}}\cdot V_{dc} + \frac{1}{C_{dc}}\cdot\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}^T\cdot\begin{pmatrix} I_{rd} \\ I_{rq} \end{pmatrix}$$

$Sol(M_{rd}, M_{rq}) := Find(I_{rd}, I_{rq}, V_{dc})$

**Se graficará para $M_{rd}$ y $M_{rq}$ en el rango -Max a Max.**

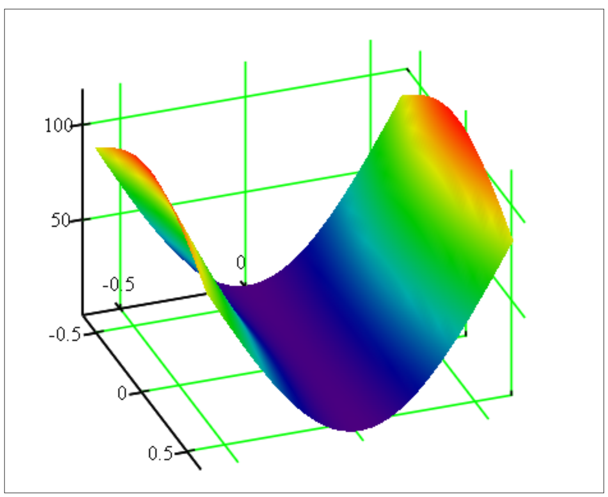
$me := 40 \quad mi_1 := -Max \quad ma_1 := Max \quad mi_2 := -Max \quad ma_2 := Max$

**A graficar $I_{rd}$, $I_{rq}$ y $V_{dc}$**

$I_{rd}(x_d, x_q) := Sol(x_d, x_q)_1 \qquad I_{rq}(x_d, x_q) := Sol(x_d, x_q)_2 \qquad V_{dc}(x_d, x_q) := Sol(x_d, x_q)_3$

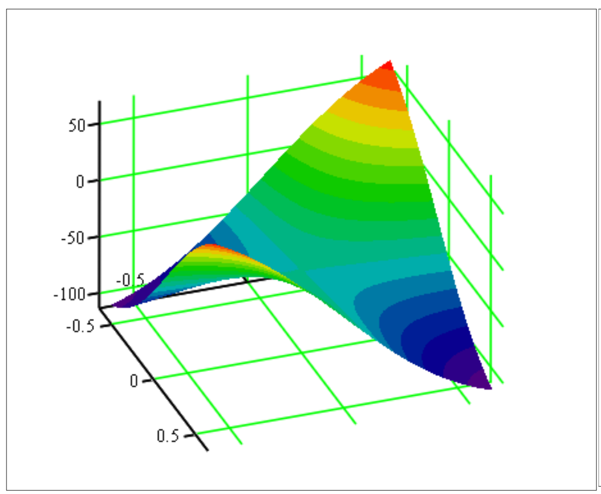
$S_{I\_rd} := CreateMesh(I_{rd}, mi_2, ma_2, mi_1, ma_1, me) \qquad S_{I\_rq} := CreateMesh(I_{rq}, mi_2, ma_2, mi_1, ma_1, me) \qquad S_{V\_dc} := CreateMesh(V_{dc}, mi_2, ma_2, mi_1, ma_1, me)$

**Corriente $I_{rd}$**



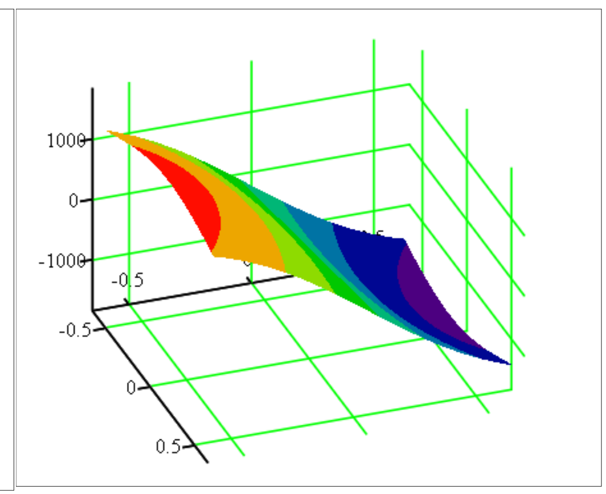
$S_{I\_rd}$

**Corriente $I_{rq}$**

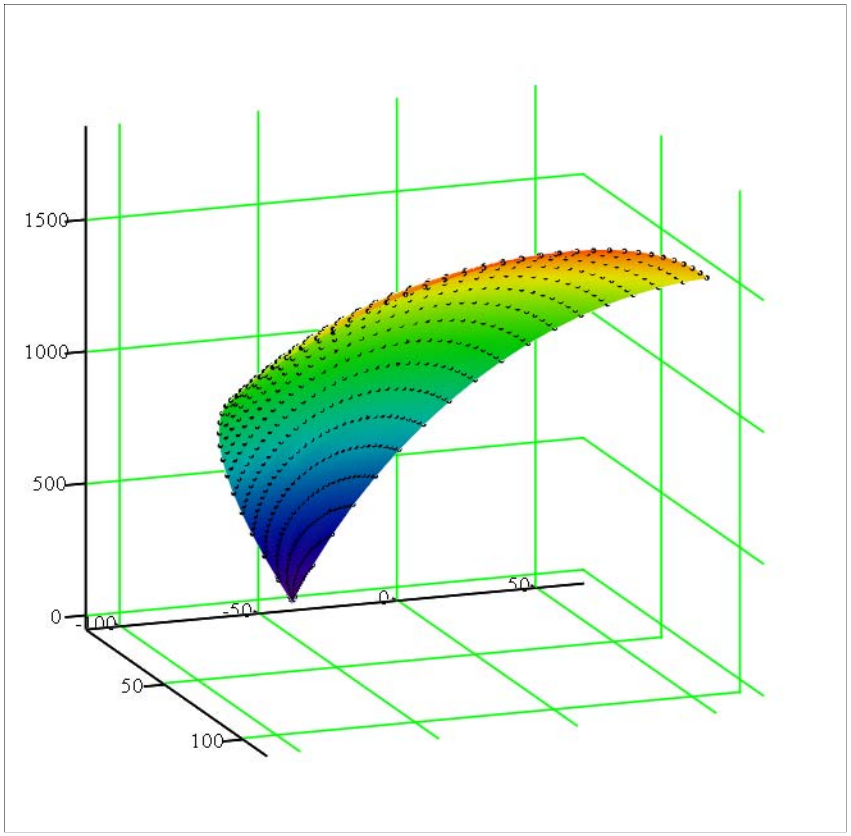


$S_{I\_rq}$

**Voltaje $V_{dc}$**



$S_{V\_dc}$

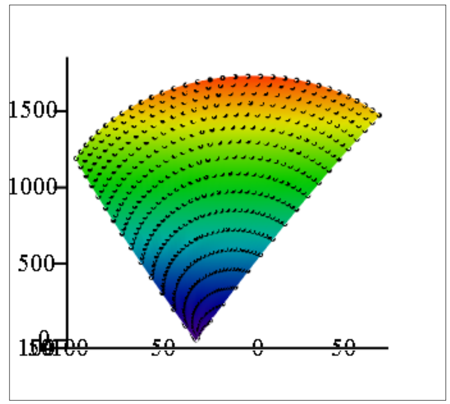



$(I_{rd}, I_{rq}, V_{dc})$

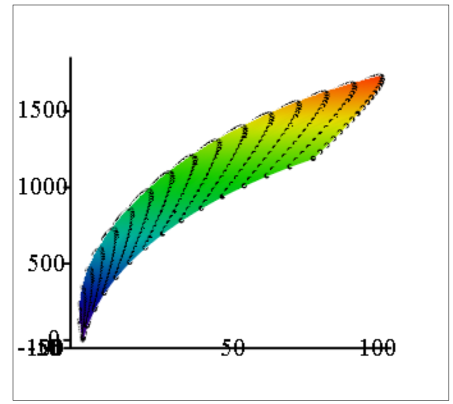
La tensión $V_{dc}$ negativa no es opción, por los diodos en antiparalelo de la topología.

Hay dos entradas $M_{rd}$ y $M_{rq}$ y hay tres variables de estado. Las potenciales salidas podrían ser $I_{rd}$ e $I_{rq}$, $I_{rd}$ y $V_{dc}$, $V_{dc}$ e $I_{rq}$.

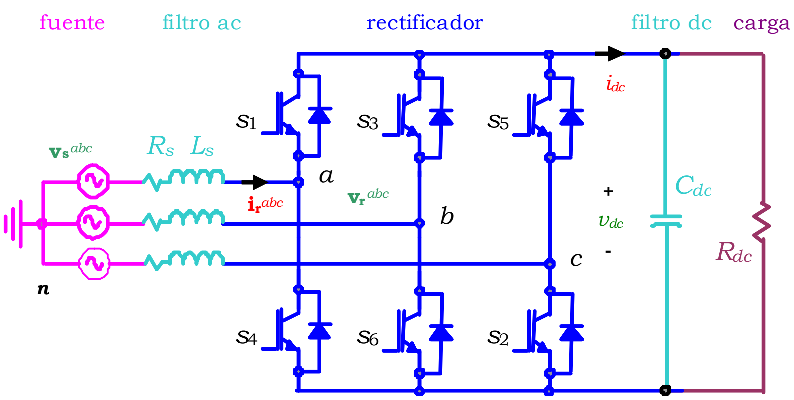
Es posible controlar $I_{rd}$ e $I_{rq}$, $V_{dc}$ e $I_{rq}$, pero **NO** se puede controlar $I_{rd}$ y $V_{dc}$ por el rango mínimo.

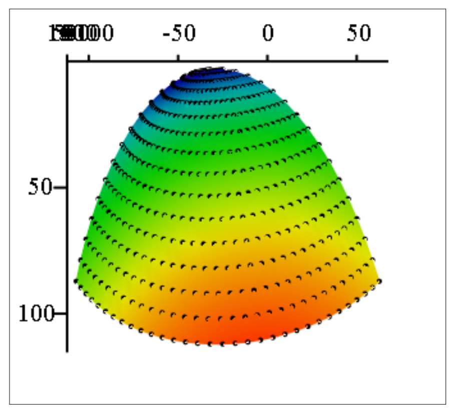



$(I_{rd}, I_{rq}, V_{dc})$




$(I_{rd}, I_{rq}, V_{dc})$



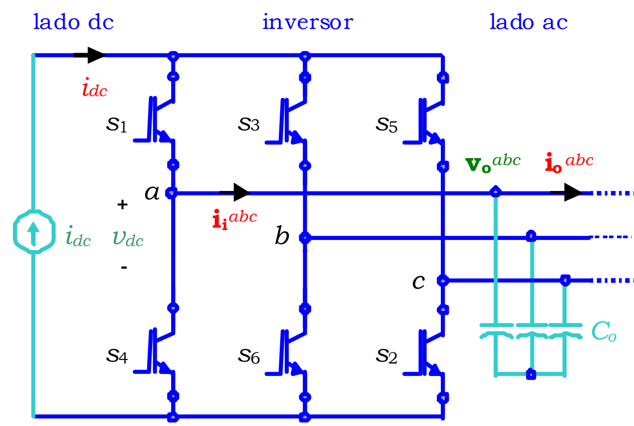




$(I_{rd}, I_{rq}, V_{dc})$

# Inversor de Corriente Trifásico



**Problema** Estudiar el inversor de corriente con Modulación SPWM.




La moduladora es, $M := 1 \quad \omega_s := 2\cdot\pi\cdot 50 \quad f_M := \frac{\pi}{6}$

$$m_a(t,M) := M\cdot\sin\left(\omega_s\cdot t + f_M - \frac{0\cdot\pi}{3}\right)$$

$$m_b(t,M) := M\cdot\sin\left(\omega_s\cdot t + f_M - \frac{2\cdot\pi}{3}\right)$$

$$m_c(t,M) := M\cdot\sin\left(\omega_s\cdot t + f_M - \frac{4\cdot\pi}{3}\right)$$

La triangular es, $f_{n\_tr} := 15 \quad per := 1$

$$tri(t) := \frac{2}{\pi}\cdot\operatorname{asin}\left(\sin\left(f_{n\_tr}\cdot\omega_s\cdot t + f_M\cdot f_{n\_tr} + \pi\right)\right)$$

Auxiliar 1 $s_x(t) := \text{if}\left(m_a(t,M) > tri(t),1,0\right)$ $\quad s_{xn}(t) := \text{if}\left(s_x(t) = 1,0,1\right)$

Auxiliar 2 $s_y(t) := \text{if}\left(m_b(t,M) > tri(t),1,0\right)$ $\quad s_{yn}(t) := \text{if}\left(s_y(t) = 1,0,1\right)$

Auxiliar 3 $s_z(t) := \text{if}\left(m_c(t,M) > tri(t),1,0\right)$ $\quad s_{zn}(t) := \text{if}\left(s_z(t) = 1,0,1\right)$

1ra pierna $s_1(t) := s_x(t)\cdot s_{zn}(t)$ $\quad s_4(t) := s_z(t)\cdot s_{xn}(t)$

2da pierna $s_3(t) := s_y(t)\cdot s_{xn}(t)$ $\quad s_6(t) := s_x(t)\cdot s_{yn}(t)$

3ra pierna $s_5(t) := s_z(t)\cdot s_{yn}(t)$ $\quad s_2(t) := s_y(t)\cdot s_{zn}(t)$

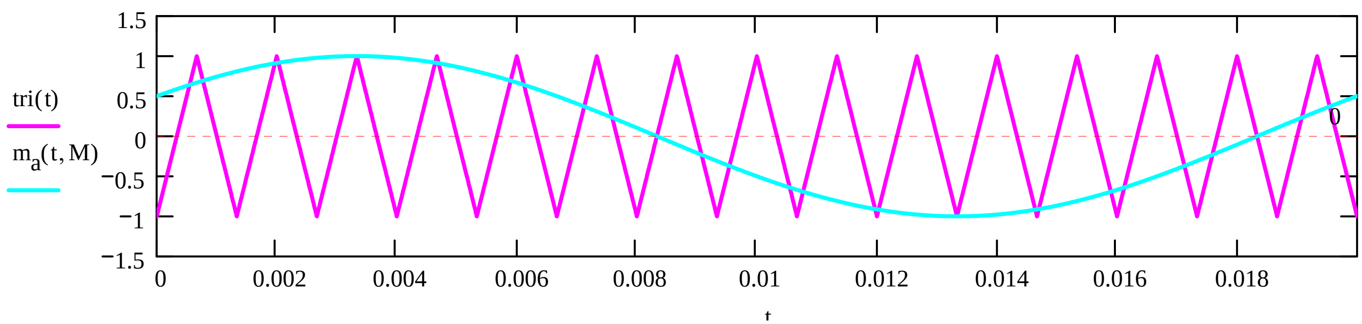
$n_f := f_{n\_tr}\cdot 4\cdot 50\cdot per \qquad n := 0\,..\,n_f \qquad t_f := .02\cdot per \qquad t := 0, \frac{t_f}{n_f}\,..\,t_f$

Las corrientes se pueden escribir como,

$$i_{ia}(t) = \left(s_1(t) - s_4(t)\right)\cdot i_{dc}(t)$$

$$i_{ib}(t) = \left(s_3(t) - s_6(t)\right)\cdot i_{dc}(t)$$

$$i_{ic}(t) = \left(s_5(t) - s_2(t)\right)\cdot i_{dc}(t)$$

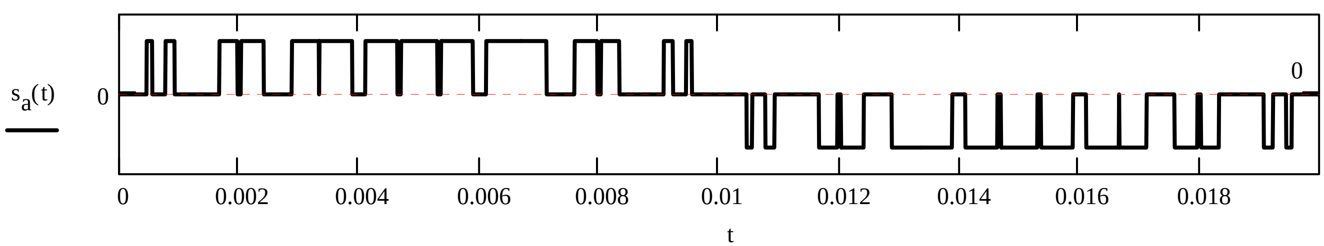



Se define la función de conmutación como,

$$s_a(t) := s_1(t) - s_4(t)$$

$$s_b(t) := s_3(t) - s_6(t)$$

$$s_c(t) := s_5(t) - s_2(t)$$

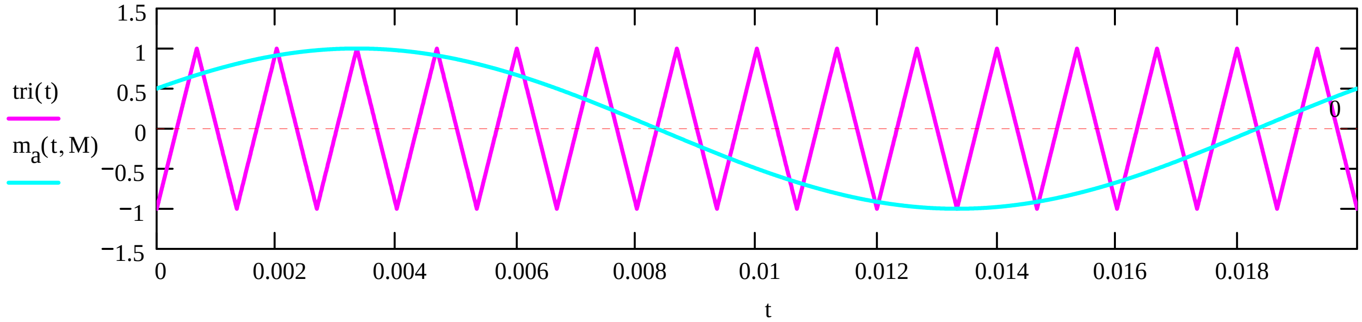


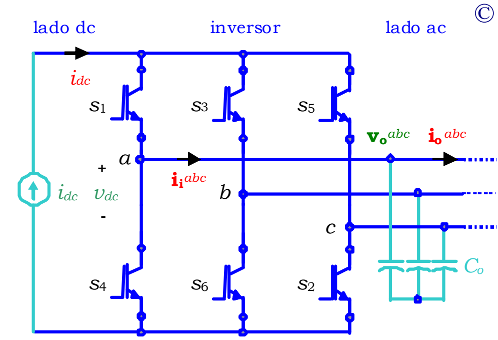

$$i_{ia}(t) = s_a(t)\cdot i_{dc}(t)$$

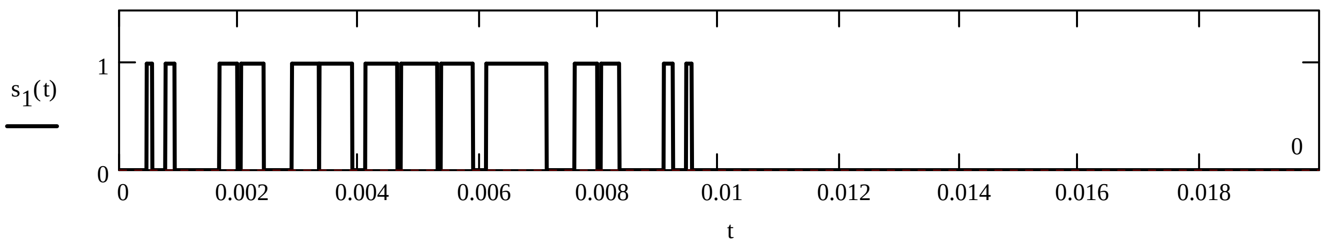
$$i_{ib}(t) = s_b(t)\cdot i_{dc}(t)$$

$$i_{ic}(t) = s_c(t)\cdot i_{dc}(t)$$

Hay un desfase entre la moduldora y la señal de conmutación.

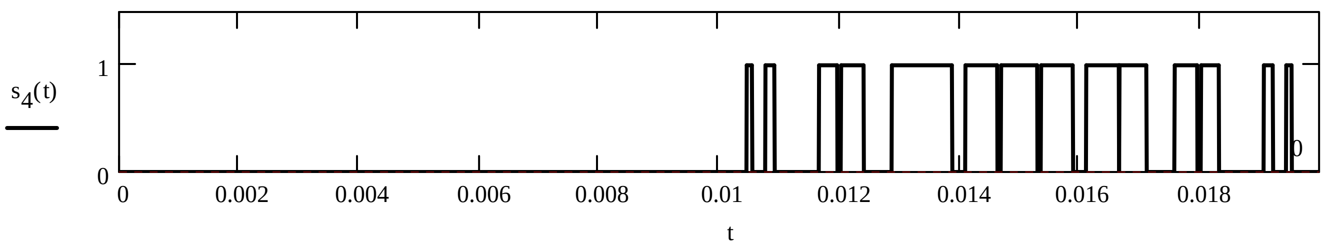


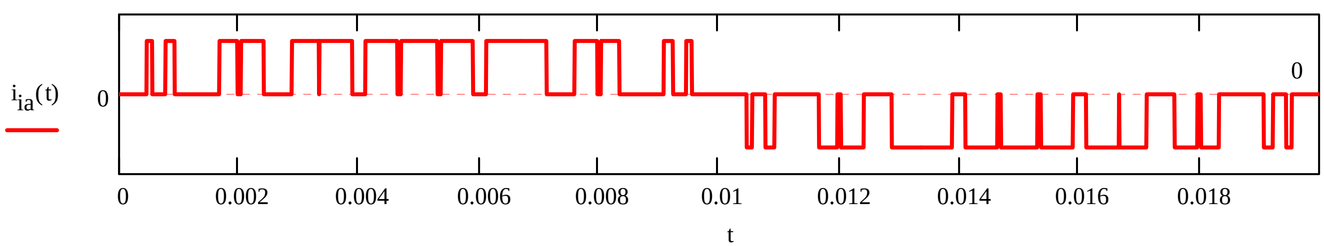




$s_a(t) := s_1(t) - s_4(t)$ $\quad I_{dc} := 10$

$i_{dc}(t) := I_{dc}$ $\quad i_{ia}(t) := s_a(t) \cdot i_{dc}(t)$




Hay un desfase entre la moduldora y la señal de conmutación.



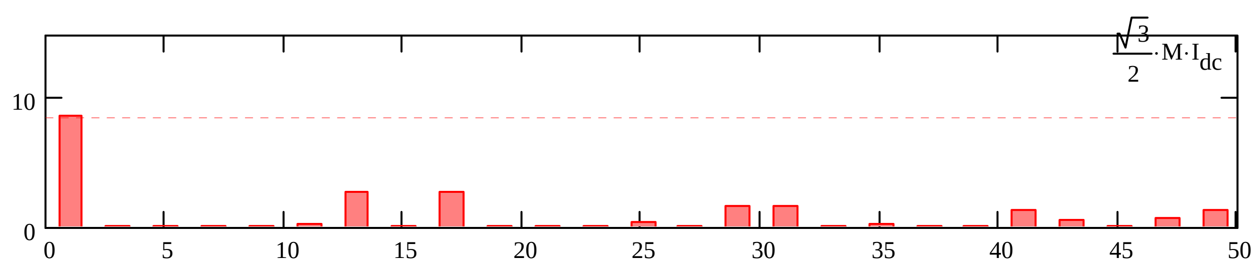

$N := 1024 \qquad m := 1..N$

$x_m := i_{ia}\left(\frac{m}{N} \cdot t_f\right) \qquad xf := FFT(x)$

$xv(m) := if(m = 1, 1, 2) \cdot xf_{m \cdot per}$

$|xv(2)| = 8.602 \qquad \frac{\sqrt{3}}{2} \cdot M \cdot I_{dc} = 8.66$

**FFT de $i_{ia}$**




**La fundamental de la corriente ac es igual a $0.866MI_{dc}$ y no hay componentes de frecuencia hasta $f_{n\_tr}$ / 2.**

La moduladora es, $M := 1 \quad \omega_s := 2\cdot\pi\cdot 50 \quad f_M := 0$

La triangular es, $f_{n\_tr} := 15 \quad per := 1$

$$tri(t) := \frac{2}{\pi}\cdot asin\left(sin\left(f_{n\_tr}\cdot\omega_s\cdot t + f_M\cdot f_{n\_tr} - \frac{\pi}{2}\right)\right)$$

$$m_a(t,M) := M\cdot sin\left(\omega_s\cdot t + f_M - \frac{0\cdot\pi}{3}\right)$$

$$m_b(t,M) := M\cdot sin\left(\omega_s\cdot t + f_M - \frac{2\cdot\pi}{3}\right)$$

$$m_c(t,M) := M\cdot sin\left(\omega_s\cdot t + f_M - \frac{4\cdot\pi}{3}\right)$$

Hay un desfase entre la moduldora y la señal de conmutación que se corrije con las señales auxiliares $m_{ax}$, $m_{bx}$ y $m_{cx}$.



Auxiliar 1 $m_{ax}(t,M) := (m_a(t,M) - m_b(t,M))\cdot(\sqrt{3})^{-1}$ $\quad s_x(t) := if(m_{ax}(t,M) > tri(t),1,0)$ $\quad s_{xn}(t) := if(s_x(t) = 1,0,1)$

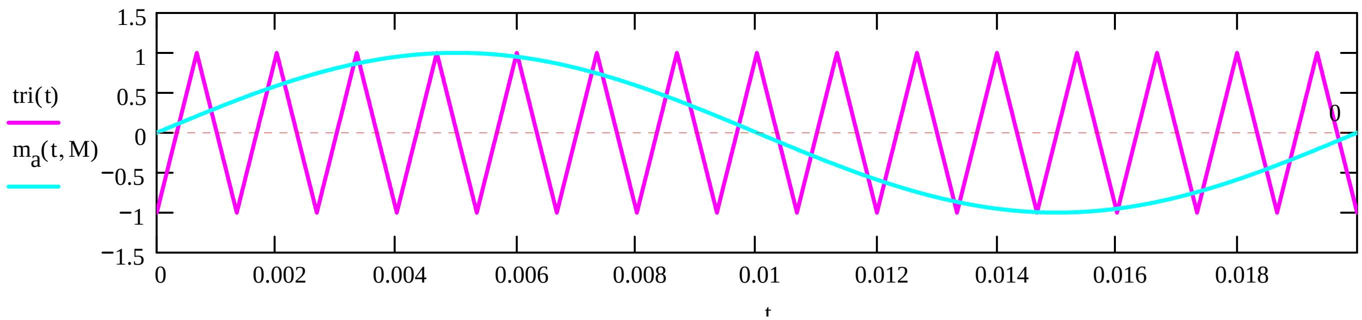
Auxiliar 2 $m_{bx}(t,M) := (m_b(t,M) - m_c(t,M))\cdot(\sqrt{3})^{-1}$ $\quad s_y(t) := if(m_{bx}(t,M) > tri(t),1,0)$ $\quad s_{yn}(t) := if(s_y(t) = 1,0,1)$

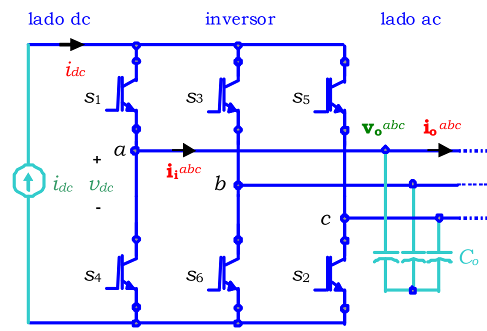
Auxiliar 3 $m_{cx}(t,M) := (m_c(t,M) - m_a(t,M))\cdot(\sqrt{3})^{-1}$ $\quad s_z(t) := if(m_{cx}(t,M) > tri(t),1,0)$ $\quad s_{zn}(t) := if(s_z(t) = 1,0,1)$

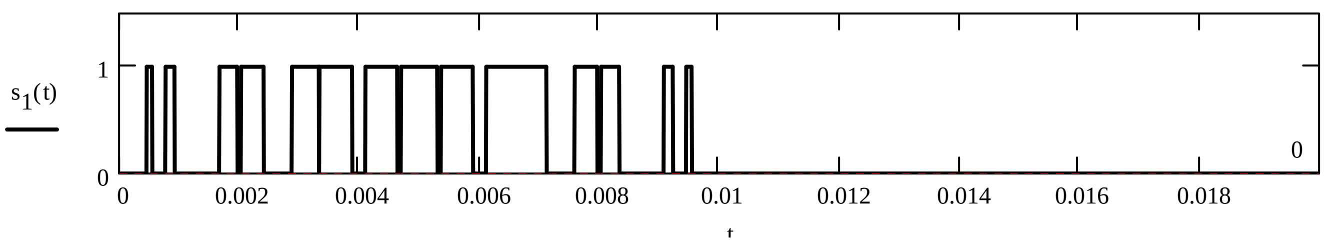
1ra pierna $s_1(t) := s_x(t)\cdot s_{zn}(t)$ $\quad s_4(t) := s_z(t)\cdot s_{xn}(t)$

2da pierna $s_3(t) := s_y(t)\cdot s_{xn}(t)$ $\quad s_6(t) := s_x(t)\cdot s_{yn}(t)$

3ra pierna $s_5(t) := s_z(t)\cdot s_{yn}(t)$ $\quad s_2(t) := s_y(t)\cdot s_{zn}(t)$



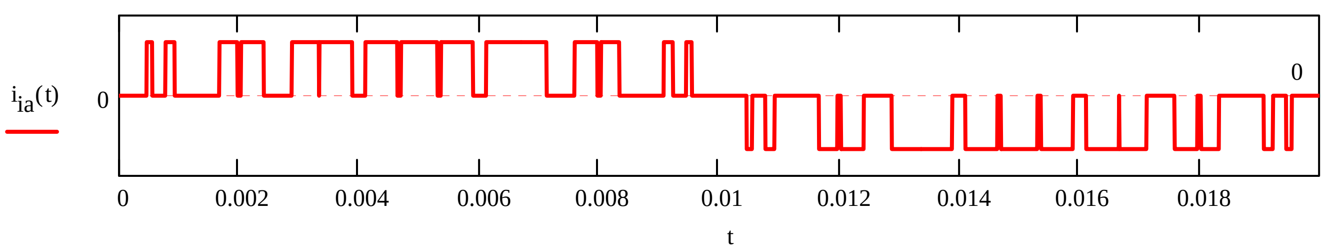




$s_a(t) := s_1(t) - s_4(t)$

$s_b(t) := s_3(t) - s_6(t)$

$s_c(t) := s_5(t) - s_2(t)$ $\quad I_{dc} := 10$

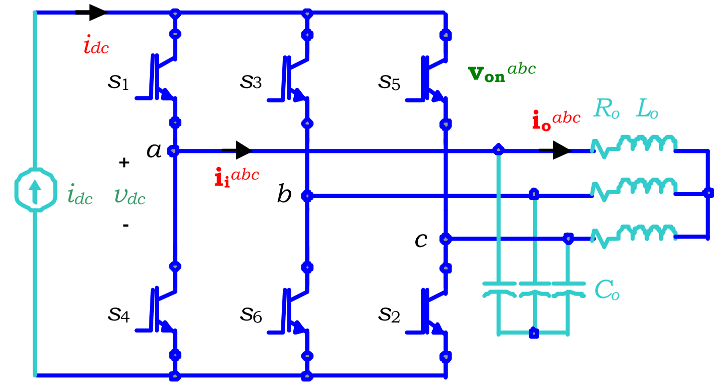
$i_{dc}(t) := I_{dc}$ $\quad i_{ia}(t) := s_a(t)\cdot i_{dc}(t)$



# Modelo de Inversor de Corriente Trifásico



**Problema** Estudiar el modelo del inversor de corriente con Modulación SPWM.




La suma de las corrientes de carga es cero y la carga es balanceada, entonces,

$$i_{i\_a}(t) = s_a(t)\cdot i_{dc}(t) = (s_1(t) - s_4(t))\cdot i_{dc}(t)$$

$$i_{i\_b}(t) = s_b(t)\cdot i_{dc}(t) = (s_3(t) - s_6(t))\cdot i_{dc}(t)$$

$$v_{o\_an}(t) + v_{o\_bn}(t) + v_{o\_cn}(t) = 0$$

$$i_{i\_c}(t) = s_c(t)\cdot i_{dc}(t) = (s_5(t) - s_2(t))\cdot i_{dc}(t)$$

$$v_{o\_an}(t) = R_o\cdot i_{o\_a}(t) + L_o\cdot di_{o\_a}(t) \qquad i_{i\_a}(t) = C_o\cdot dv_{o\_an}(t) + i_{o\_a}(t)$$

$$v_{o\_bn}(t) = R_o\cdot i_{o\_b}(t) + L_o\cdot di_{o\_b}(t) \qquad i_{i\_b}(t) = C_o\cdot dv_{o\_bn}(t) + i_{o\_b}(t)$$

$$v_{o\_cn}(t) = R_o\cdot i_{o\_c}(t) + L_o\cdot di_{o\_c}(t) \qquad i_{i\_c}(t) = C_o\cdot dv_{o\_cn}(t) + i_{o\_c}(t)$$

$$v_{dc}(t)\cdot i_{dc}(t) = v_{o\_n}(t)^T\cdot i_i(t)$$

$$v_{o\_n}(t) = R_o\cdot i_o(t) + L_o\cdot di_o(t)$$

$$s_i(t) := \begin{pmatrix} s_a(t) \\ s_b(t) \\ s_c(t) \end{pmatrix}$$

$$i_i(t) = s_i(t)\cdot i_{dc}(t)$$

$$s_i(t)\cdot i_{dc}(t) = C_o\cdot dv_{o\_n}(t) + i_o(t)$$

$$v_{dc}(t)\cdot i_{dc}(t) = v_{o\_n}(t)^T\cdot s_i(t)\cdot i_{dc}(t)$$

$$v_{dc}(t) = v_{o\_n}(t)^T\cdot s_i(t)$$

$$di_o(t) = \frac{-R_o}{L_o}\cdot i_o(t) + \frac{1}{L_o}\cdot v_{o\_n}(t) \qquad dv_{o\_n}(t) = \frac{-1}{C_o}\cdot i_o(t) + \frac{1}{C_o}\cdot s_i(t)\cdot i_{dc}(t)$$

$$v_{dc}(t) = v_{o\_n}(t)^T\cdot s_i(t)$$

Parámetros

$L_o := 15\cdot 10^{-3}$ $\quad R_o := 10$ $\quad C_o := 100\cdot 10^{-6}$ $\quad i_{dc}(t) := I_{dc}$

Simulación $\quad t_f := 0.02 \quad n_f := 2048 \quad n := 1..n_f \quad t := 0, \frac{t_f}{n_f} .. t_f$

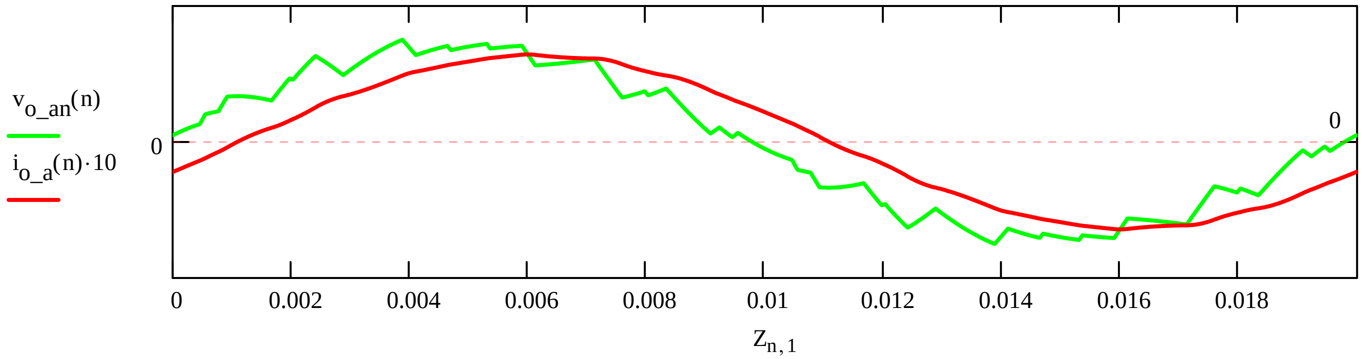
$$D(t,x) := \text{stack}\left(\frac{-R_o}{L_o}\cdot(x_1\ x_2\ x_3)^T + \frac{1}{L_o}\cdot(x_4\ x_5\ x_6)^T, \frac{-1}{C_o}\cdot(x_1\ x_2\ x_3)^T + \frac{1}{C_o}\cdot s_i(t)\cdot i_{dc}(t)\right)$$

$$CI := \text{stack}\left[\begin{pmatrix}0\\0\\0\end{pmatrix},\begin{pmatrix}0\\0\\0\end{pmatrix}\right] \qquad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$$

$$CI := \text{stack}\left((Z_{n_f,2}\ Z_{n_f,3}\ Z_{n_f,4})^T, (Z_{n_f,5}\ Z_{n_f,6}\ Z_{n_f,7})^T\right) \qquad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$$

$v_{o\_an}(n) := Z_{n,5}$ $\quad v_{o\_bn}(n) := Z_{n,6}$ $\quad v_{o\_cn}(n) := Z_{n,7}$ $\quad i_{i\_a}(n) := s_i\left(n\cdot\frac{t_f}{n_f}\right)\cdot i_{dc}\left(n\cdot\frac{t_f}{n_f}\right)$

$i_{o\_a}(n) := Z_{n,2}$ $\quad i_{o\_b}(n) := Z_{n,3}$ $\quad i_{o\_c}(n) := Z_{n,4}$ $\quad v_{dc}(n) := \left(v_{o\_an}(n)\ \ v_{o\_bn}(n)\ \ v_{o\_cn}(n)\right)^T\cdot s_i\left(n\cdot\frac{t_f}{n_f}\right)$



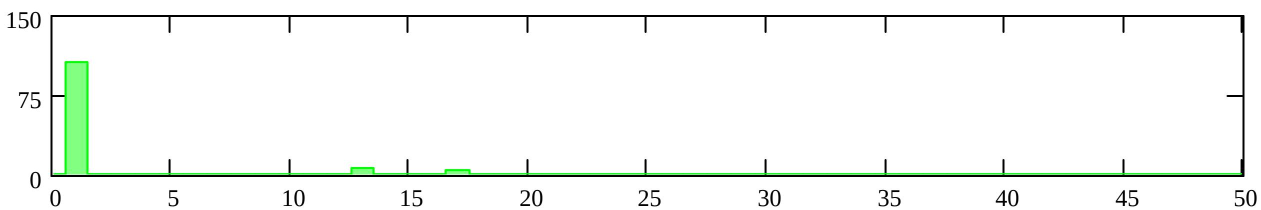

$N := 1024$ $\quad m := 1..N$

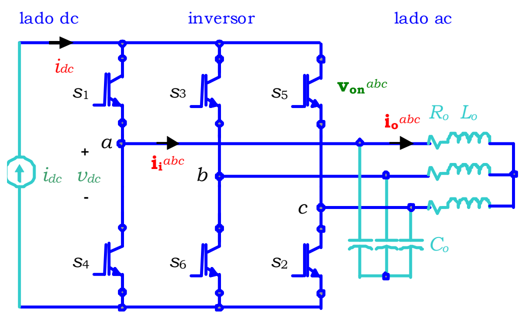
$x_m := v_{o\_an}\left(\frac{m}{N}\cdot n_f\right)$ $\quad xf := FFT(x)$

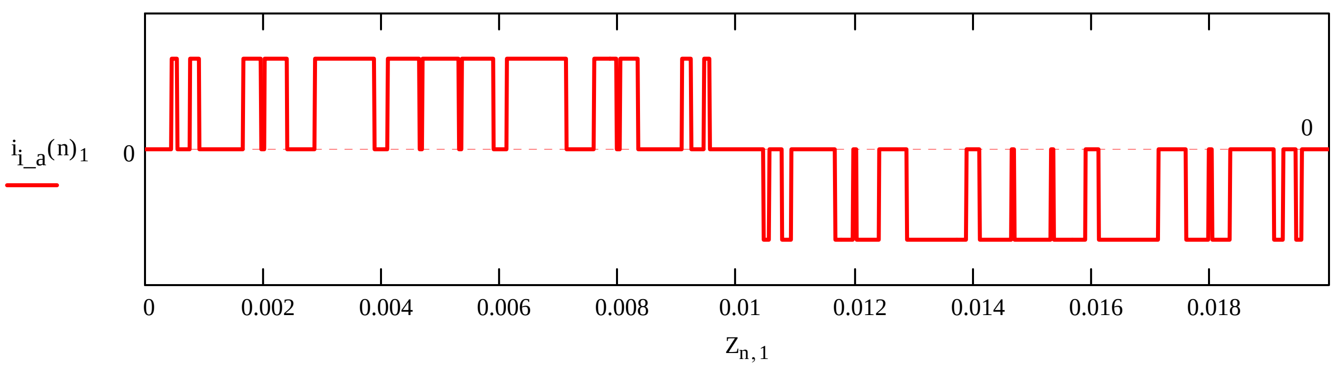
$xv(m) := if(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(2)| = 105.242$

**FFT de $v_{o\_an}$**




$N := 1024$ $\quad m := 1..N$

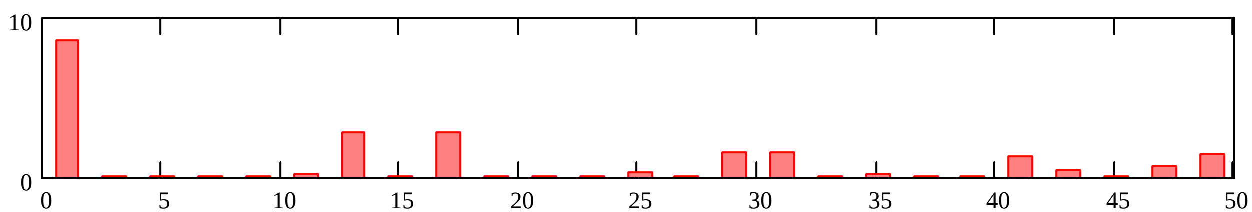
$x_m := i_{i\_a}\left(\frac{m}{N}\cdot n_f\right)_1$ $\quad xf := FFT(x)$

$xv(m) := if(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(2)| = 8.602$

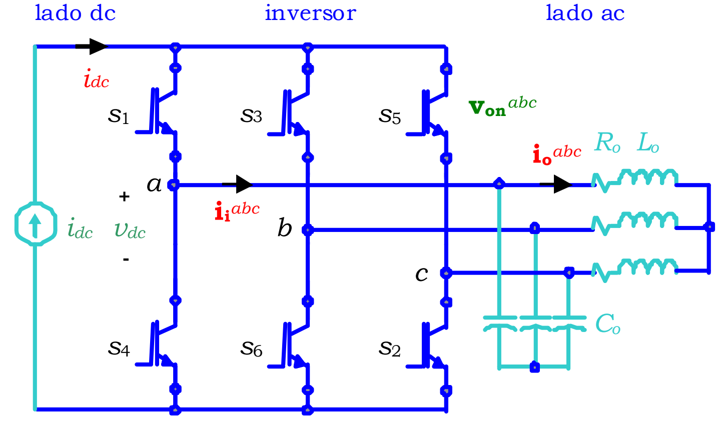
$\frac{\sqrt{3}}{2}\cdot M\cdot I_{dc} = 8.66$

**FFT de $i_{dc}$**




**La fundamental de la corriente ac es igual a $0.866MI_{dc}$ y están en fase.**

**Problema** Estudiar el modelo promedio del inversor de corriente.




Se utiliza la relación entre la fundamental de corriente y la moduladora.

$$\begin{pmatrix} i_{i\_a}(t) \\ i_{i\_b}(t) \\ i_{i\_c}(t) \end{pmatrix} = \frac{\sqrt{3}}{2} \cdot \begin{pmatrix} m_a(t) \\ m_b(t) \\ m_c(t) \end{pmatrix} \cdot i_{dc}(t)$$

$$v_{o\_an}(t) = R_o \cdot i_{o\_a}(t) + L_o \cdot di_{o\_a}(t) \qquad i_{i\_a}(t) = C_o \cdot dv_{o\_an}(t) + i_{o\_a}(t)$$

$$v_{o\_bn}(t) = R_o \cdot i_{o\_b}(t) + L_o \cdot di_{o\_b}(t) \qquad i_{i\_b}(t) = C_o \cdot dv_{o\_bn}(t) + i_{o\_b}(t)$$

$$v_{o\_cn}(t) = R_o \cdot i_{o\_c}(t) + L_o \cdot di_{o\_c}(t) \qquad i_{i\_c}(t) = C_o \cdot dv_{o\_cn}(t) + i_{o\_c}(t)$$

$$v_{dc}(t) \cdot i_{dc}(t) = v_{o\_n}(t)^T \cdot i_i(t)$$

$$i_i(t) = m_i(t) \cdot i_{dc}(t)$$

$$v_{o\_n}(t) = R_o \cdot i_o(t) + L_o \cdot di_o(t)$$

$$m_i(t) \cdot i_{dc}(t) = C_o \cdot dv_{o\_n}(t) + i_o(t)$$

$$m_i(t) := \frac{\sqrt{3}}{2} \cdot \begin{pmatrix} m_a(t,M) \\ m_b(t,M) \\ m_c(t,M) \end{pmatrix}$$

$$v_{dc}(t) \cdot i_{dc}(t) = v_{o\_n}(t)^T \cdot m_i(t) \cdot i_{dc}(t)$$

$$v_{dc}(t) = v_{o\_n}(t)^T \cdot m_i(t)$$

$$di_o(t) = \frac{-R_o}{L_o} \cdot i_o(t) + \frac{1}{L_o} \cdot v_{o\_n}(t) \qquad dv_{o\_n}(t) = \frac{-1}{C_o} \cdot i_o(t) + \frac{1}{C_o} \cdot m_i(t) \cdot i_{dc}(t)$$

$$v_{dc}(t) = v_{o\_n}(t)^T \cdot m_i(t)$$

Parámetros

$L_o := 15 \cdot 10^{-3}$ $\quad R_o := 10$ $\quad C_o := 100 \cdot 10^{-6}$ $\quad i_{dc}(t) := I_{dc}$

Simulación $\quad t_f := 0.02 \quad n_f := 2048 \quad n := 1 .. n_f \quad t := 0, \frac{t_f}{n_f} .. t_f$

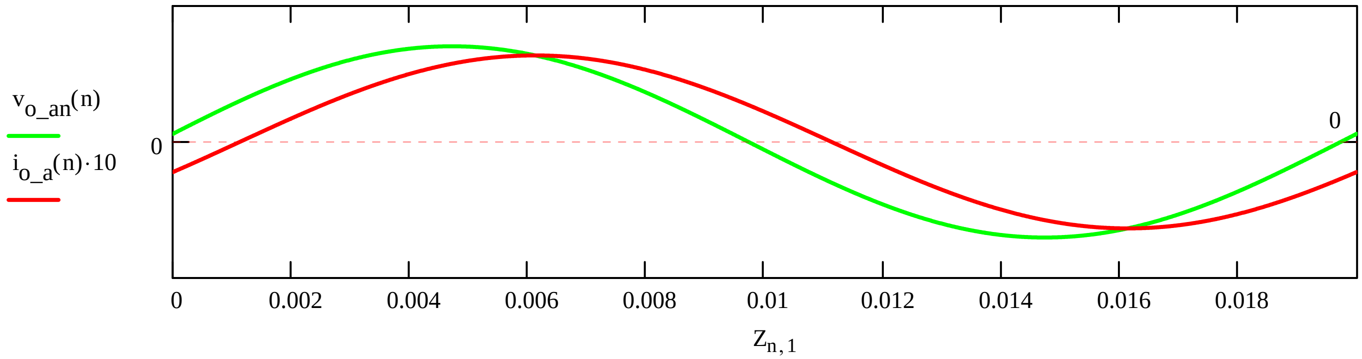
$$D(t,x) := \text{stack}\left( \frac{-R_o}{L_o} \cdot \left(x_1 \;\; x_2 \;\; x_3\right)^T + \frac{1}{L_o} \cdot \left(x_4 \;\; x_5 \;\; x_6\right)^T, \frac{-1}{C_o} \cdot \left(x_1 \;\; x_2 \;\; x_3\right)^T + \frac{1}{C_o} \cdot m_i(t) \cdot i_{dc}(t) \right)$$

$$CI := \text{stack}\left[ \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \right] \qquad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$$

$$CI := \text{stack}\left( \left(Z_{n_f,2} \;\; Z_{n_f,3} \;\; Z_{n_f,4}\right)^T, \left(Z_{n_f,5} \;\; Z_{n_f,6} \;\; Z_{n_f,7}\right)^T \right) \qquad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$$

$v_{o\_an}(n) := Z_{n,5}$ $\quad v_{o\_bn}(n) := Z_{n,6}$ $\quad v_{o\_cn}(n) := Z_{n,7}$ $\quad i_{i\_a}(n) := m_i\left(n\cdot\frac{t_f}{n_f}\right)\cdot i_{dc}\left(n\cdot\frac{t_f}{n_f}\right)$

$i_{o\_a}(n) := Z_{n,2}$ $\quad i_{o\_b}(n) := Z_{n,3}$ $\quad i_{o\_c}(n) := Z_{n,4}$ $\quad v_{dc}(n) := \left(v_{o\_an}(n)\;\; v_{o\_bn}(n)\;\; v_{o\_cn}(n)\right)^T\cdot m_i\left(n\cdot\frac{t_f}{n_f}\right)$



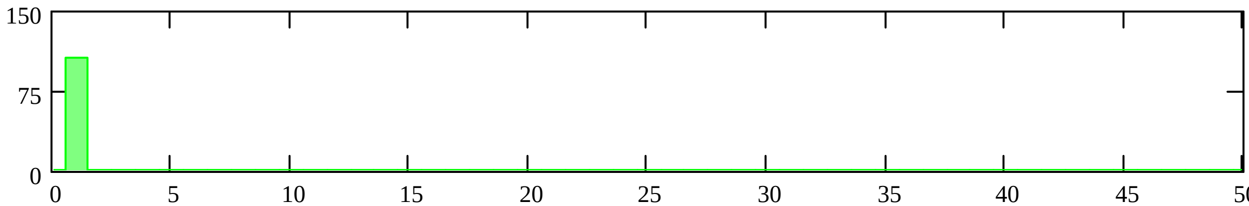

$N := 1024$ $\quad m := 1 .. N$

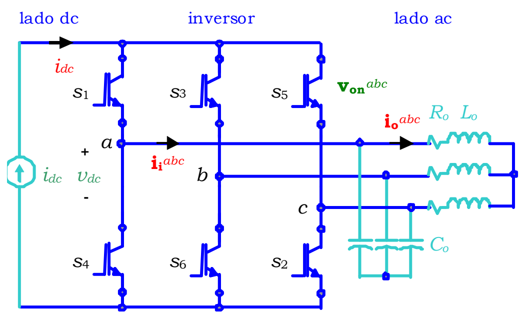
$x_m := v_{o\_an}\left(\frac{m}{N}\cdot n_f\right)$ $\quad xf := FFT(x)$

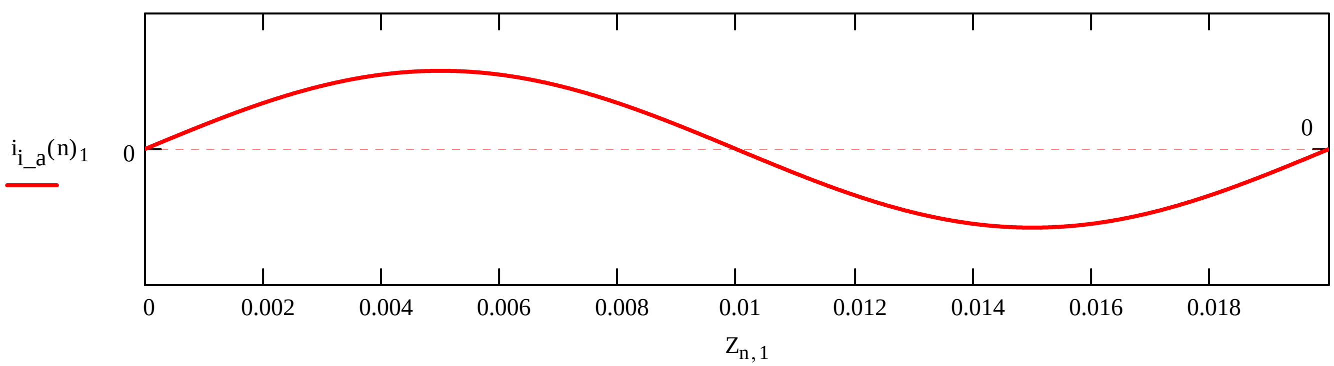
$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(2)| = 105.456$

**FFT de $v_{o\_an}$**




$N := 1024$ $\quad m := 1 .. N$

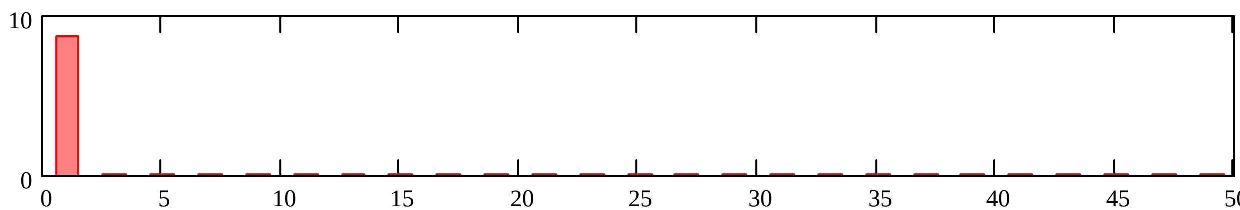
$x_m := i_{i\_a}\left(\frac{m}{N}\cdot n_f\right)_1$ $\quad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(2)| = 8.66$

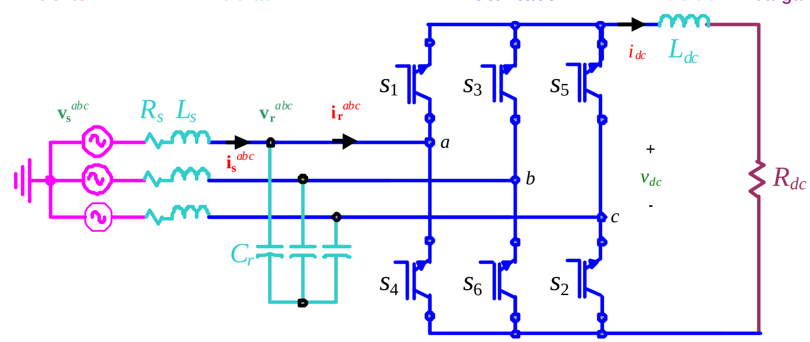
$\frac{\sqrt{3}}{2}\cdot M\cdot I_{dc} = 8.66$

**FFT de $i_{dc}$**




**La fundamental de la corriente ac es igual a 0.866MI$_{dc}$ y están en fase.**

**Problema** Estudiar el modelo del rectificador de corriente con Modulación SPWM.




$i_{r\_a}(t) = s_a(t)\cdot i_{dc}(t) = \left(s_1(t) - s_4(t)\right)\cdot i_{dc}(t)$

$i_{r\_b}(t) = s_b(t)\cdot i_{dc}(t) = \left(s_3(t) - s_6(t)\right)\cdot i_{dc}(t)$

$i_{r\_c}(t) = s_c(t)\cdot i_{dc}(t) = \left(s_5(t) - s_2(t)\right)\cdot i_{dc}(t)$

Parámetros

$L_s := 30\cdot 10^{-3}$ $R_s := 1$

$C_r := 50\cdot 10^{-6}$ $R_{dc} := 10$

$L_{dc} := 30\cdot 10^{-3}$

$v_{s\_a}(t) = R_s\cdot i_{s\_a}(t) + L_s\cdot di_{s\_a}(t) + v_{r\_an}(t)$

$v_{s\_b}(t) = R_s\cdot i_{s\_b}(t) + L_s\cdot di_{s\_b}(t) + v_{r\_bn}(t)$

$v_{s\_c}(t) = R_s\cdot i_{s\_c}(t) + L_s\cdot di_{s\_c}(t) + v_{r\_cn}(t)$

$i_{s\_a}(t) = i_{r\_a}(t) + C_r\cdot dv_{r\_an}(t)$

$i_{s\_b}(t) = i_{r\_b}(t) + C_r\cdot dv_{r\_bn}(t)$

$i_{s\_c}(t) = i_{r\_c}(t) + C_r\cdot dv_{r\_cn}(t)$

$v_{dc}(t) = L_{dc}\cdot di_{dc}(t) + R_{dc}\cdot i_{dc}(t)$

$v_{dc}(t)\cdot i_{dc}(t) = v_{r\_n}(t)^T\cdot i_r(t)$

$i_r(t) = s_r(t)\cdot i_{dc}(t)$

$v_{dc}(t)\cdot i_{dc}(t) = v_{r\_n}(t)^T\cdot s_r(t)\cdot i_{dc}(t)$

$v_{dc}(t) = v_{r\_n}(t)^T\cdot s_r(t)$

$v_{dc}(t) = v_{r\_n}(t)^T\cdot s_r(t)$

$v_s(t) = R_s\cdot i_s(t) + L_s\cdot di_s(t) + v_{r\_n}(t)$

$i_s(t) = C_r\cdot dv_{r\_n}(t) + s_r(t)\cdot i_{dc}(t)$

$v_{r\_n}(t)^T\cdot s_r(t) = L_{dc}\cdot di_{dc}(t) + R_{dc}\cdot i_{dc}(t)$

$$di_s(t) = \frac{-R_s}{L_s}\cdot i_s(t) - \frac{1}{L_s}\cdot v_{r\_n}(t) + \frac{1}{L_s}\cdot v_s(t)$$

$$dv_{r\_n}(t) = \frac{-1}{C_r}\cdot s_r(t)\cdot i_{dc}(t) + \frac{1}{C_r}\cdot i_s(t)$$

$$di_{dc}(t) = \frac{-R_{dc}}{L_{dc}}\cdot i_{dc}(t) + \frac{1}{L_{dc}}\cdot v_{r\_n}(t)^T\cdot s_r(t)$$

$$v_s(t) := \left(\sqrt{2}\cdot 220\cdot\sin(\omega_s\cdot t)\quad \sqrt{2}\cdot 220\cdot\sin\left(\omega_s\cdot t - 2\cdot\frac{\pi}{3}\right)\quad \sqrt{2}\cdot 220\cdot\sin\left(\omega_s\cdot t - 4\cdot\frac{\pi}{3}\right)\right)^T$$

$s_r(t) := s_i(t)$

Simulación $t_f := 0.02$ $n_f := 2048$ $n := 1 .. n_f$ $t := 0, \frac{t_f}{n_f} .. t_f$

$$D(t,x) := \text{stack}\left(\frac{-R_s}{L_s}\cdot(x_1\ \ x_2\ \ x_3)^T - \frac{1}{L_s}\cdot(x_4\ \ x_5\ \ x_6)^T + \frac{1}{L_s}\cdot v_s(t), \frac{-1}{C_r}\cdot s_r(t)\cdot x_7 + \frac{1}{C_r}\cdot(x_1\ \ x_2\ \ x_3)^T, \frac{-R_{dc}}{L_{dc}}\cdot x_7 + \frac{1}{L_{dc}}\cdot(x_4\ \ x_5\ \ x_6)^T\cdot s_r(t)\right)$$

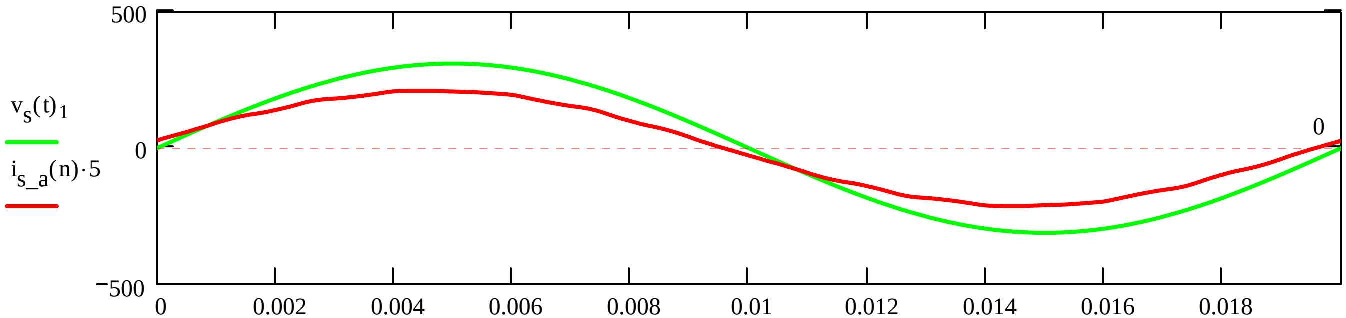
$CI := (5.537\ \ -38.684\ \ 33.281\ \ -371.682\ \ -81.54\ \ 490.274\ \ 43.18)^T$ $Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

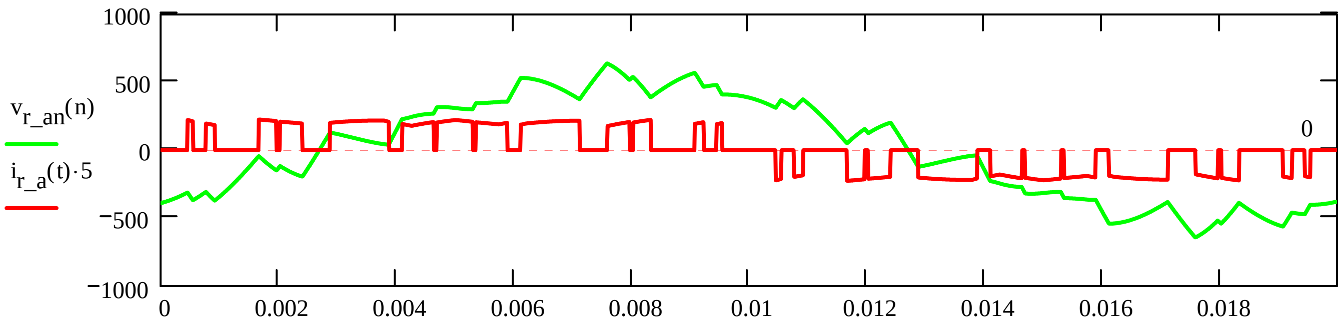
$CI := \left(Z_{n_f,2}\ \ Z_{n_f,3}\ \ Z_{n_f,4}\ \ Z_{n_f,5}\ \ Z_{n_f,6}\ \ Z_{n_f,7}\ \ Z_{n_f,8}\right)^T$ $Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

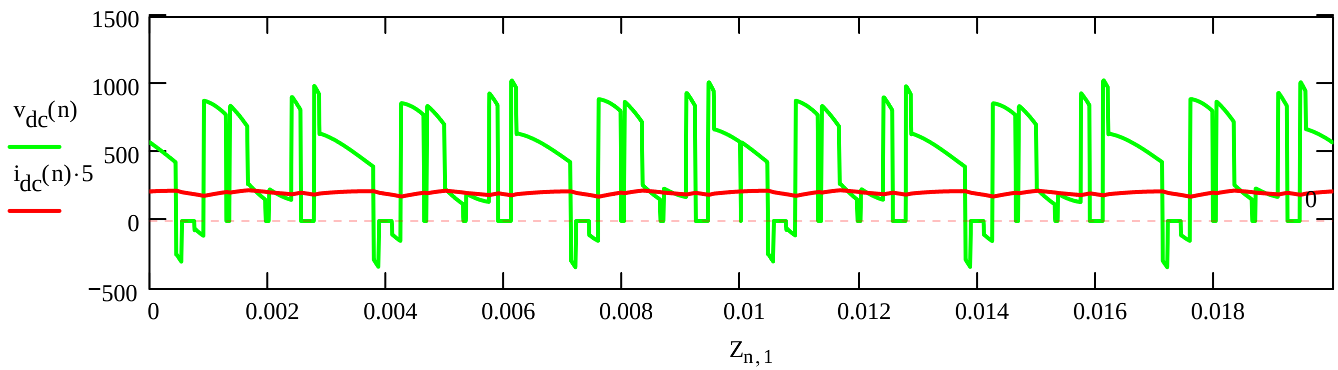
$$i_{dc}(n) := Z_{n,8} \qquad i_{r\_a}(t) := \left(s_r(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_1 \qquad i_{r\_b}(t) := \left(s_r(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_2 \qquad i_{r\_c}(t) := \left(s_r(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_3$$

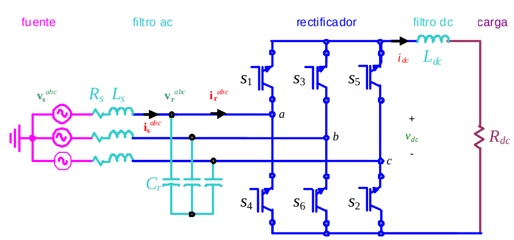
$$i_{s\_a}(n) := Z_{n,2} \qquad i_{s\_b}(n) := Z_{n,3} \qquad i_{s\_c}(n) := Z_{n,4} \qquad v_{r\_an}(n) := Z_{n,5} \quad v_{r\_bn}(n) := Z_{n,6} \quad v_{r\_cn}(n) := Z_{n,7}$$

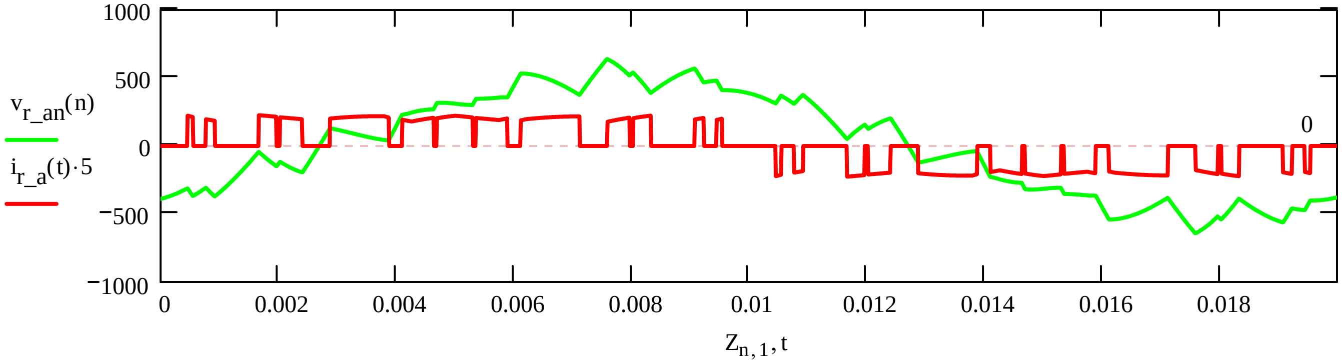
$$v_{dc}(n) := s_r\left(n\cdot\frac{t_f}{n_f}\right)^T \cdot \left(v_{r\_an}(n) \;\; v_{r\_bn}(n) \;\; v_{r\_cn}(n)\right)^T$$






$N := 1024$ $\quad m := 1 .. N$

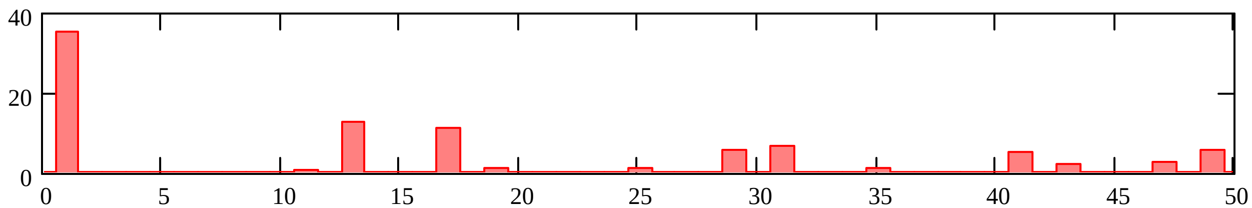
$x_m := i_{r\_a}\left(\frac{m}{N}\cdot t_f\right)$ $\quad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

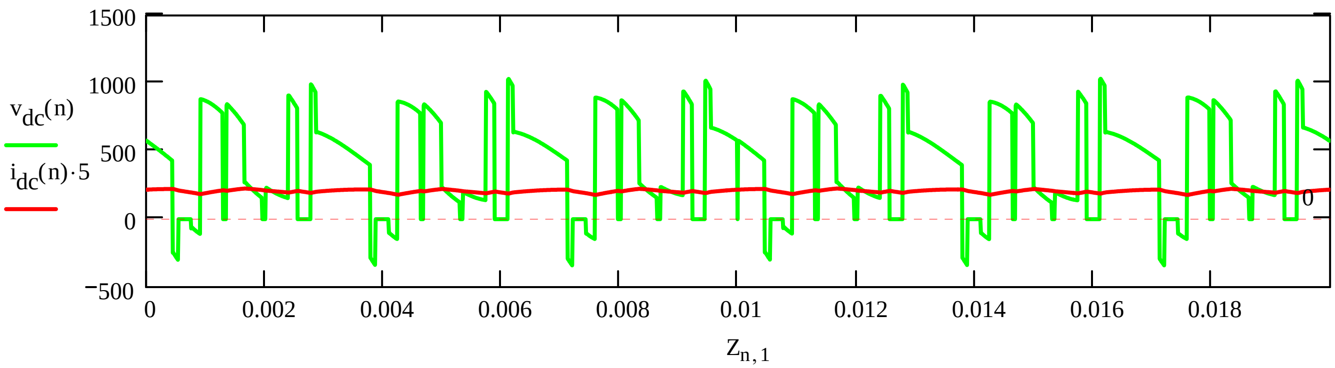
$|xv(2)| = 35.445$

$\frac{\sqrt{3}}{2}\cdot M\cdot i_{dc}(1) = 37.524$

**FFT de $i_{r\_a}$**




**La fundamental de corriente es igual a 0.866 M $I_{dc}$**




$N := 1024$ $\quad m := 1 .. N$

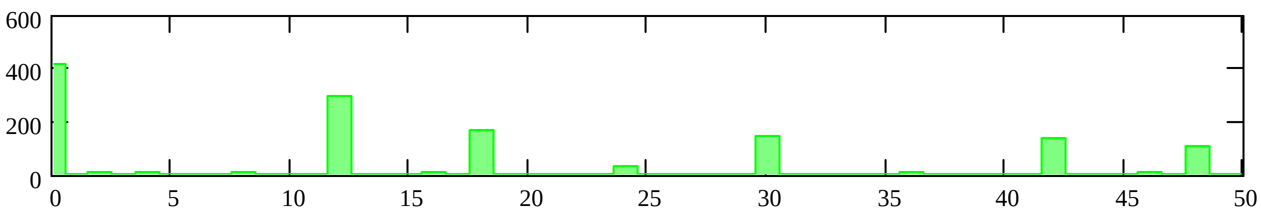
$x_m := v_{dc}\left(\frac{m}{N}\cdot n_f\right)$ $\quad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(1)| = 413.522$ $\quad V_{dc} := |xv(1)|$

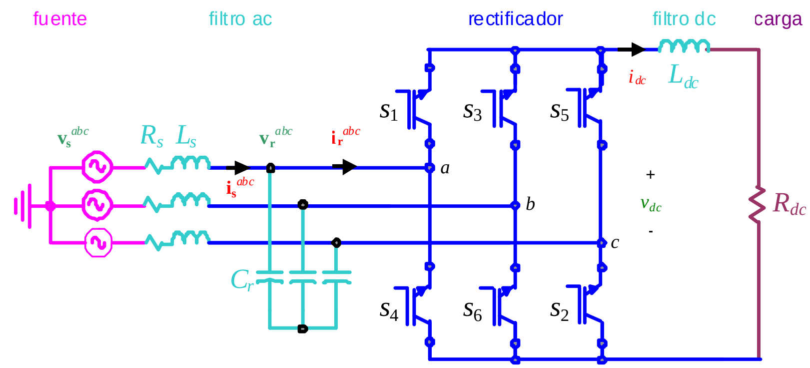
$P_o := \frac{V_{dc}^2}{R_{dc}}$ $\quad P_o = 1.71 \times 10^4$

**FFT de $v_{dc}$**




**El voltaje DC no tiene segunda armónica. Sólo armónicas de conmutación.**

**Problema** Estudiar el modelo promedio del rectificador de corriente.




$$\begin{pmatrix} i_{r\_a}(t) \\ i_{r\_b}(t) \\ i_{r\_c}(t) \end{pmatrix} = \frac{\sqrt{3}}{2} \cdot \begin{pmatrix} m_a(t) \\ m_b(t) \\ m_c(t) \end{pmatrix} \cdot i_{dc}(t)$$

Parámetros

$L_s := 30 \cdot 10^{-3}$  $R_s := 1$

$C_r := 50 \cdot 10^{-6}$  $R_{dc} := 10$

$L_{dc} := 30 \cdot 10^{-3}$

$$v_{s\_a}(t) = R_s \cdot i_{s\_a}(t) + L_s \cdot di_{s\_a}(t) + v_{r\_an}(t)$$

$$v_{s\_b}(t) = R_s \cdot i_{s\_b}(t) + L_s \cdot di_{s\_b}(t) + v_{r\_bn}(t)$$

$$v_{s\_c}(t) = R_s \cdot i_{s\_c}(t) + L_s \cdot di_{s\_c}(t) + v_{r\_cn}(t)$$

$$i_{s\_a}(t) = i_{r\_a}(t) + C_r \cdot dv_{r\_an}(t)$$

$$i_{s\_b}(t) = i_{r\_b}(t) + C_r \cdot dv_{r\_bn}(t)$$

$$i_{s\_c}(t) = i_{r\_c}(t) + C_r \cdot dv_{r\_cn}(t)$$

$$v_{dc}(t) = L_{dc} \cdot di_{dc}(t) + R_{dc} \cdot i_{dc}(t)$$

$$v_{dc}(t) \cdot i_{dc}(t) = v_{r\_n}(t)^T \cdot i_r(t)$$

$$i_r(t) = m_r(t) \cdot i_{dc}(t)$$

$$v_{dc}(t) \cdot i_{dc}(t) = v_{r\_n}(t)^T \cdot m_r(t) \cdot i_{dc}(t)$$

$$v_{dc}(t) = v_{r\_n}(t)^T \cdot m_r(t)$$

$$v_{dc}(t) = v_{r\_n}(t)^T \cdot m_r(t)$$

$$v_s(t) = R_s \cdot i_s(t) + L_s \cdot di_s(t) + v_{r\_n}(t)$$

$$i_s(t) = C_r \cdot dv_{r\_n}(t) + m_r(t) \cdot i_{dc}(t)$$

$$v_{r\_n}(t)^T \cdot m_r(t) = L_{dc} \cdot di_{dc}(t) + R_{dc} \cdot i_{dc}(t)$$

$$di_s(t) = \frac{-R_s}{L_s} \cdot i_s(t) - \frac{1}{L_s} \cdot v_{r\_n}(t) + \frac{1}{L_s} \cdot v_s(t)$$

$$dv_{r\_n}(t) = \frac{-1}{C_r} \cdot m_r(t) \cdot i_{dc}(t) + \frac{1}{C_r} \cdot i_s(t)$$

$$di_{dc}(t) = \frac{-R_{dc}}{L_{dc}} \cdot i_{dc}(t) + \frac{1}{L_{dc}} \cdot v_{r\_n}(t)^T \cdot m_r(t)$$

$$v_s(t) := \left( \sqrt{2} \cdot 220 \cdot \sin(\omega_s \cdot t) \quad \sqrt{2} \cdot 220 \cdot \sin\left(\omega_s \cdot t - 2 \cdot \frac{\pi}{3}\right) \quad \sqrt{2} \cdot 220 \cdot \sin\left(\omega_s \cdot t - 4 \cdot \frac{\pi}{3}\right) \right)^T$$

$$m_r(t) := \frac{\sqrt{3}}{2} \cdot \begin{pmatrix} m_a(t, M) \\ m_b(t, M) \\ m_c(t, M) \end{pmatrix}$$

Simulación $t_f := 0.02$  $n_f := 2048$  $n := 1 .. n_f$  $t := 0, \frac{t_f}{n_f} .. t_f$

$$D(t,x) := \text{stack}\left( \frac{-R_s}{L_s} \cdot (x_1 \ x_2 \ x_3)^T - \frac{1}{L_s} \cdot (x_4 \ x_5 \ x_6)^T + \frac{1}{L_s} \cdot v_s(t), \frac{-1}{C_r} \cdot m_r(t) \cdot x_7 + \frac{1}{C_r} \cdot (x_1 \ x_2 \ x_3)^T, \frac{-R_{dc}}{L_{dc}} \cdot x_7 + \frac{1}{L_{dc}} \cdot (x_4 \ x_5 \ x_6)^T \cdot m_r(t) \right)$$

$$CI := (4.868 \quad -38.653 \quad 33.835 \quad -398.658 \quad -69.957 \quad 475.516 \quad 41.046)^T$$

$$Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$$

$$CI := \left( Z_{n_f,2} \ Z_{n_f,3} \ Z_{n_f,4} \ Z_{n_f,5} \ Z_{n_f,6} \ Z_{n_f,7} \ Z_{n_f,8} \right)^T$$

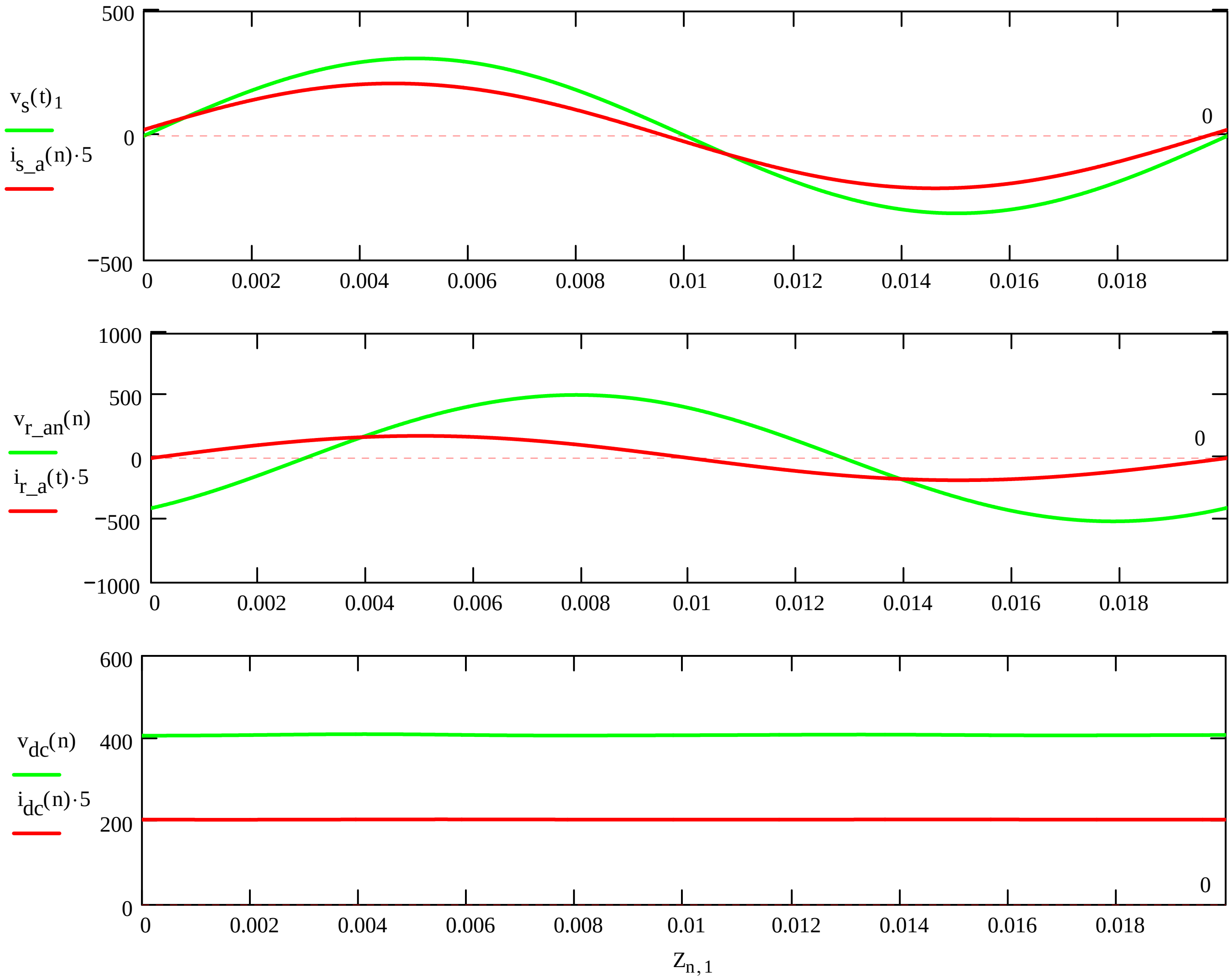
$$Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$$

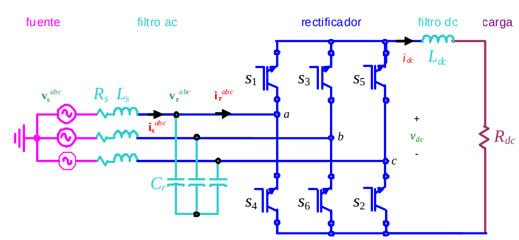
$$i_{dc}(n) := Z_{n,8} \qquad i_{r\_a}(t) := \left(m_r(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_1 \qquad i_{r\_b}(t) := \left(m_r(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_2 \qquad i_{r\_c}(t) := \left(m_r(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_3$$

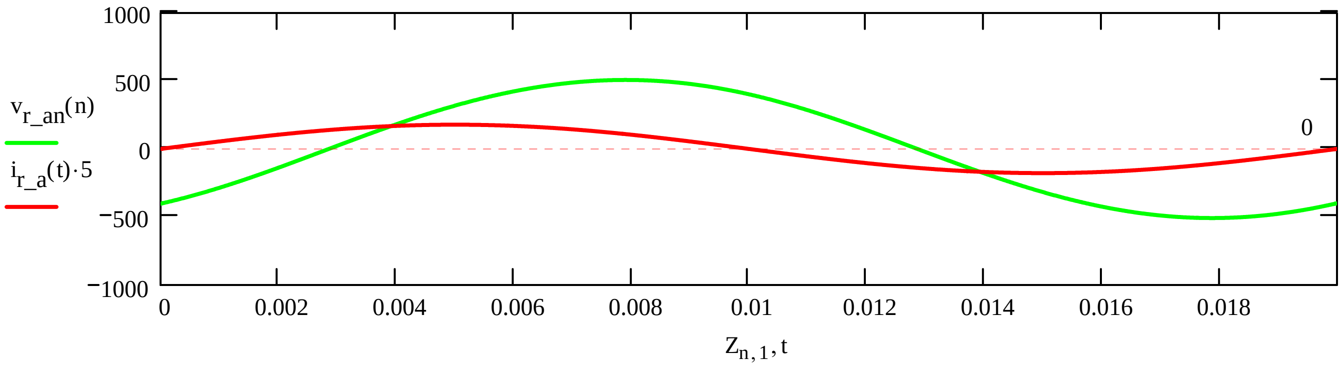


$$i_{s\_a}(n) := Z_{n,2} \qquad i_{s\_b}(n) := Z_{n,3} \qquad i_{s\_c}(n) := Z_{n,4} \qquad v_{r\_an}(n) := Z_{n,5} \quad v_{r\_bn}(n) := Z_{n,6} \quad v_{r\_cn}(n) := Z_{n,7}$$

$$v_{dc}(n) := m_r\left(n\cdot\frac{t_f}{n_f}\right)^T\cdot\left(v_{r\_an}(n)\ \ v_{r\_bn}(n)\ \ v_{r\_cn}(n)\right)^T$$






$N := 1024$ $\quad m := 1 .. N$

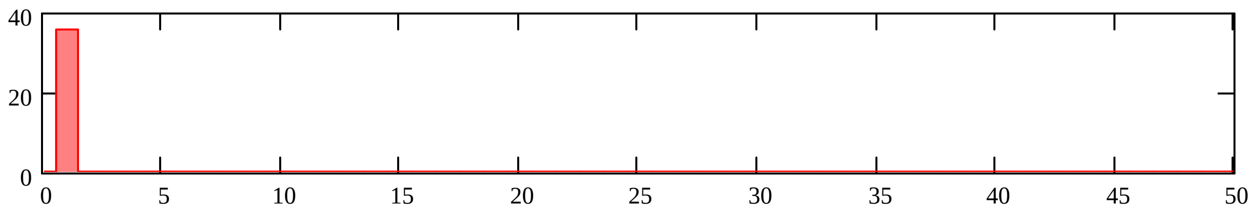
$x_m := i_{r\_a}\left(\frac{m}{N}\cdot t_f\right)$ $\quad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

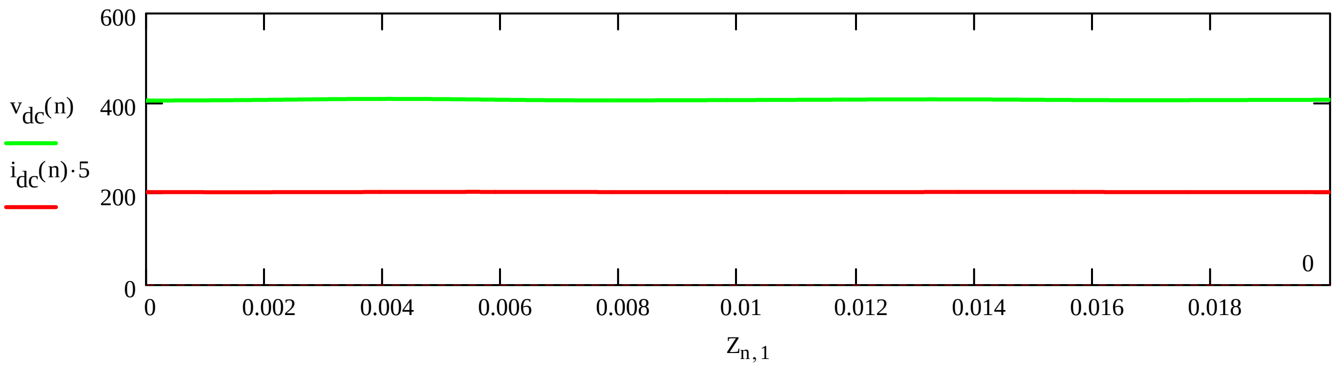
$|xv(2)| = 35.586$

$\frac{\sqrt{3}}{2}\cdot M\cdot i_{dc}(1) = 35.545$

**FFT de $i_{r\_a}$**




**La fundamental de corriente es igual a 0.866 M $I_{dc}$**




$N := 1024$ $\quad m := 1 .. N$

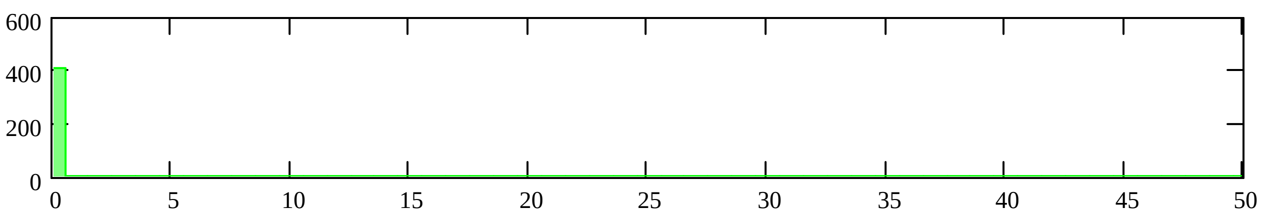
$x_m := v_{dc}\left(\frac{m}{N}\cdot n_f\right)$ $\quad xf := FFT(x)$

$xv(m) := \text{if}(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(1)| = 409.071$ $\quad V_{dc} := |xv(1)|$

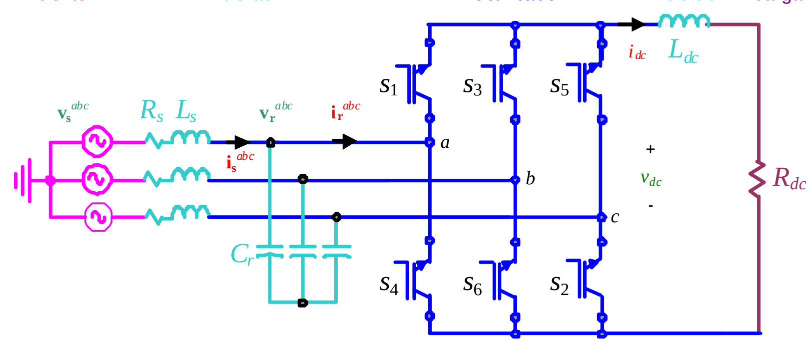
$P_o := \frac{V_{dc}^2}{R_{dc}}$ $\quad P_o = 1.673\times 10^4$

**FFT de $v_{dc}$**




**El voltaje DC no tiene segunda armónica.**

**Problema** Estudiar el modelo promedio dq0 del rectificador de corriente.




$$i_{rdq}(t) = m_{rdq}(t)\cdot i_{dc}(t)$$

$$v_{dc}(t) = v_{rdq\_n}(t)^T\cdot m_{rdq}(t)$$

$$v_{sdq}(t) = R_s\cdot i_{sdq}(t) + L_s\cdot\left(di_{sdq}(t) + W\cdot i_{sdq}(t)\right) + v_{rdq\_n}(t)$$

$$i_{sdq}(t) = C_r\cdot\left(dv_{rdq\_n}(t) + W\cdot v_{rdq\_n}(t)\right) + m_{rdq}(t)\cdot i_{dc}(t)$$

$$v_{rdq\_n}(t)^T\cdot m_{rdq}(t) = L_{dc}\cdot di_{dc}(t) + R_{dc}\cdot i_{dc}(t)$$

$$di_{sdq}(t) = -W\cdot i_{sdq}(t) + \frac{-R_s}{L_s}\cdot i_{sdq}(t) - \frac{1}{L_s}\cdot v_{rdq\_n}(t) + \frac{1}{L_s}\cdot v_{sdq}(t)$$

$$dv_{rdq\_n}(t) = -W\cdot v_{rdq\_n}(t) + \frac{-1}{C_r}\cdot m_{rdq}(t)\cdot i_{dc}(t) + \frac{1}{C_r}\cdot i_{sdq}(t)$$

$$di_{dc}(t) = \frac{-R_{dc}}{L_{dc}}\cdot i_{dc}(t) + \frac{1}{L_{dc}}\cdot v_{rdq\_n}(t)^T\cdot m_{rdq}(t)$$

$$v_{sdq}(t) := \left(\sqrt{3}\cdot 220 \quad 0\right)^T$$

### Parámetros

$L_s := 30\cdot 10^{-3}$ $\quad R_s := 1$

$C_r := 50\cdot 10^{-6}$ $\quad R_{dc} := 10$

$L_{dc} := 30\cdot 10^{-3}$

$$W := \begin{pmatrix} 0 & -\omega_s \\ \omega_s & 0 \end{pmatrix}$$

$$m_{rdq}(t) := \sqrt{\frac{2}{3}}\cdot\begin{pmatrix} \sin(\omega_s\cdot t) & \sin\left(\omega_s\cdot t - 2\cdot\frac{\pi}{3}\right) & \sin\left(\omega_s\cdot t - 4\cdot\frac{\pi}{3}\right) \\ \cos(\omega_s\cdot t) & \cos\left(\omega_s\cdot t - 2\cdot\frac{\pi}{3}\right) & \cos\left(\omega_s\cdot t - 4\cdot\frac{\pi}{3}\right) \end{pmatrix}\cdot m_r(t)$$

### Simulación

$t_f := 0.02 \qquad n_f := 2048 \qquad n := 1..n_f \qquad t := 0, \frac{t_f}{n_f} .. t_f$

$$D(t,x) := \text{stack}\left(-W\cdot(x_1 \ \ x_2)^T + \frac{-R_s}{L_s}\cdot(x_1 \ \ x_2)^T - \frac{1}{L_s}\cdot(x_3 \ \ x_4)^T + \frac{1}{L_s}\cdot v_{sdq}(t), -W\cdot(x_3 \ \ x_4)^T + \frac{-1}{C_r}\cdot m_{rdq}(t)\cdot x_5 + \frac{1}{C_r}\cdot(x_1 \ \ x_2)^T, \frac{-R_{dc}}{L_{dc}}\cdot x_5 + \frac{1}{L_{dc}}\cdot(x_3 \ \ x_4)^T\cdot m_{rdq}(t)\right)$$

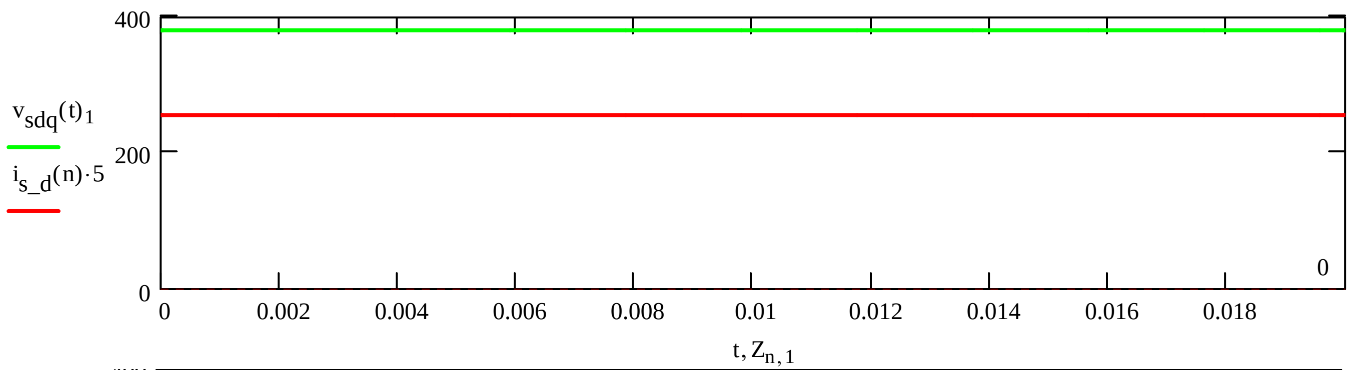
$CI := (51.206 \quad 6.078 \quad 386.785 \quad -488.94 \quad 41.089)^T$ $\qquad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

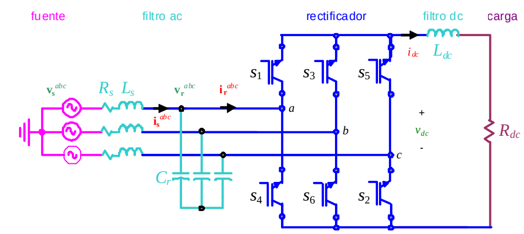
$CI := \left(Z_{n_f,2} \quad Z_{n_f,3} \quad Z_{n_f,4} \quad Z_{n_f,5} \quad Z_{n_f,6}\right)^T$ $\qquad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$

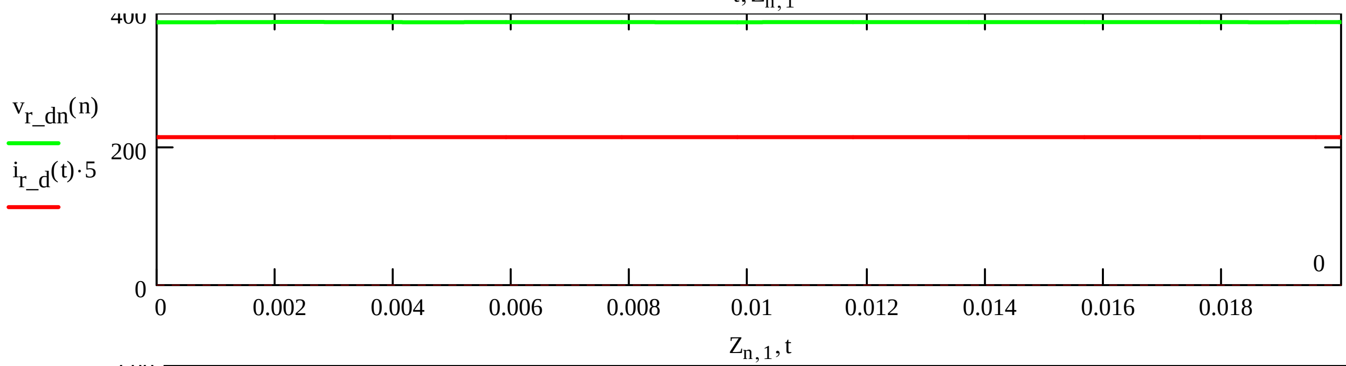
$i_{dc}(n) := Z_{n,6}$ $\quad i_{r\_d}(t) := \left(m_{rdq}(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_1$ $\quad i_{r\_q}(t) := \left(m_{rdq}(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_2$

$i_{s\_d}(n) := Z_{n,2}$ $\quad i_{s\_q}(n) := Z_{n,3}$ $\quad v_{r\_dn}(n) := Z_{n,4}$ $\quad v_{r\_qn}(n) := Z_{n,5}$

$$v_{dc}(n) := m_{rdq}\left(n\cdot\frac{t_f}{n_f}\right)^T\cdot\left(v_{r\_dn}(n) \quad v_{r\_qn}(n)\right)^T$$

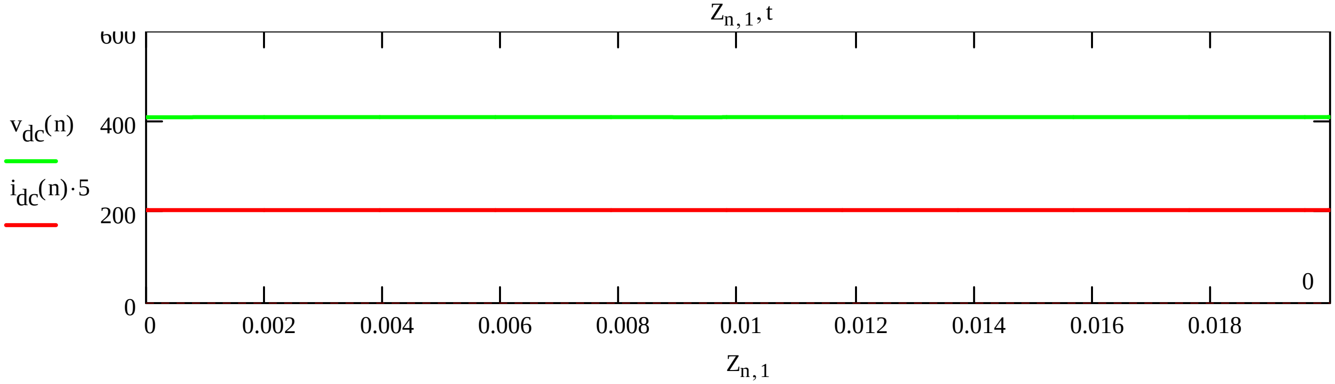



$$\sqrt{i_{r\_d}(0.01)^2 + i_{r\_q}(0.01)^2}\cdot\sqrt{\frac{2}{3}} = 35.557$$

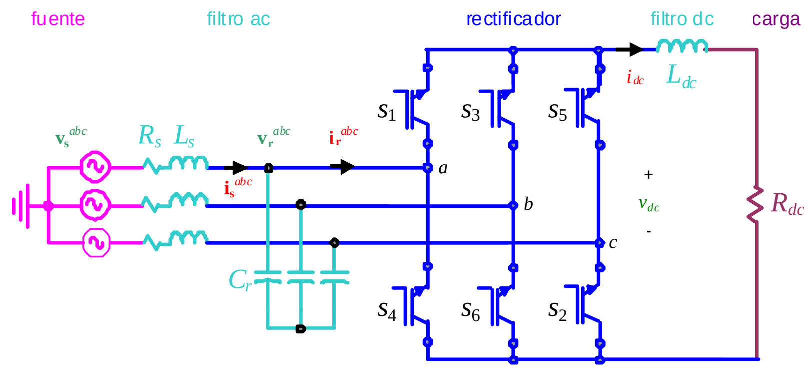
$$\sqrt{\frac{2}{3}}\cdot\left|m_{rdq}(0.01)\right|\cdot i_{dc}(1) = 35.557$$




$$\frac{\sqrt{3}}{2}\cdot M\cdot i_{dc}(1) = 35.557$$

**La fundamental de ir es 0.866 M $I_{dc}$**

**Problema** Encontrar un punto de operación




$\phi_0 := -30\cdot\frac{\pi}{180}$ $\quad P_{dc\_0} := 4000$ $\quad \begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} := \begin{pmatrix} \sqrt{3}\cdot 220 \\ 0 \end{pmatrix}$

c.i. para Given/Find que deben ser igual en número al número de incógnitas

$\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} := \begin{pmatrix} 10 \\ -6 \end{pmatrix}$ $\quad \begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} := \begin{pmatrix} 300 \\ 0 \end{pmatrix}$ $\quad \begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix} := \begin{pmatrix} 0.5 \\ 0.0 \end{pmatrix}$ $\quad I_{dc} := 20$

Given

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W\cdot\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} + \frac{-R_s}{L_s}\cdot\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} - \frac{1}{L_s}\cdot\begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} + \frac{1}{L_s}\cdot\begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix}$$

$$0 = \frac{-R_{dc}}{L_{dc}}\cdot I_{dc} + \frac{1}{L_{dc}}\cdot\begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix}^T\cdot\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}$$

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W\cdot\begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} + \frac{-1}{C_r}\cdot\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}\cdot I_{dc} + \frac{1}{C_r}\cdot\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix}$$

$$\phi_0 = \operatorname{atan}\left(\frac{I_{sq}}{I_{sd}}\right) \qquad P_{dc\_0} = R_{dc}\cdot I_{dc}^2$$

$$\begin{pmatrix} I_{sd} & I_{sq} & V_{rd} & V_{rq} & I_{dc} & M_{rd} & M_{rq} \end{pmatrix} := \operatorname{Find}(I_{sd}, I_{sq}, V_{rd}, V_{rq}, I_{dc}, M_{rd}, M_{rq})^T$$

$m_{rdq}(t) := \begin{pmatrix} M_{rd} & M_{rq} \end{pmatrix}^T$

$$\begin{pmatrix} I_{sd} & I_{sq} & V_{rd} & V_{rq} & I_{dc} & M_{rd} & M_{rq} \end{pmatrix} = (10.914 \quad -6.301 \quad 310.749 \quad -96.562 \quad 20 \quad 0.47 \quad -0.559)$$

Ángulo de Corriente

$\phi := \operatorname{atan}\left(\frac{I_{sq}}{I_{sd}}\right)$

$\phi\cdot\frac{180}{\pi} = -30$

Potencia en la Carga

$P_{dc\_0} := R_{dc}\cdot I_{dc}^2$

$P_{dc\_0}\cdot 10^{-3} = 4$

Ampl. Mod. en abc

$M_r := \frac{2}{\sqrt{3}}\cdot\sqrt{\frac{2}{3}}\cdot\sqrt{(M_{rd})^2 + (M_{rq})^2}$

$M_r = 0.689$

Filtro AC

$L_s\cdot 10^3 = 30$

$C_r\cdot 10^6 = 50$

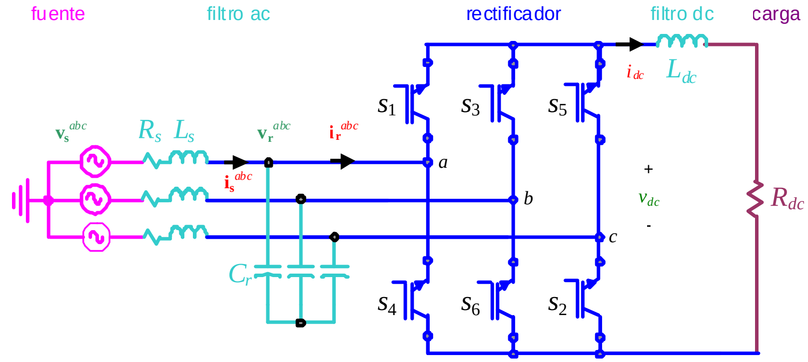
Frec. de Resonancia:

$\omega_{rn} := \left(\omega_s\cdot\sqrt{L_s\cdot C_r}\right)^{-1}$

$\omega_{rn} = 2.599$

**¿ Especificar un índice de modulación $M_r$ ?**

**Problema** Encontrar un punto de operación




$\phi_0 \cdot \frac{180}{\pi} = -30$ $P_{dc\_0} = 4 \times 10^3$ $M_r := 0.8$

c.i. para Given/Find que deben ser igual en número al número de incógnitas

$\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} = \begin{pmatrix} 10.914 \\ -6.301 \end{pmatrix}$ $\begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} = \begin{pmatrix} 310.749 \\ -96.562 \end{pmatrix}$ $\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix} = \begin{pmatrix} 0.47 \\ -0.559 \end{pmatrix}$ $I_{dc} := 20$

Given

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W \cdot \begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} + \frac{-R_s}{L_s} \cdot \begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} - \frac{1}{L_s} \cdot \begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} + \frac{1}{L_s} \cdot \begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix}$$

$$0 = \frac{-R_{dc}}{L_{dc}} \cdot I_{dc} + \frac{1}{L_{dc}} \cdot \begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix}^T \cdot \begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}$$

$$M_r = \frac{2}{\sqrt{3}} \cdot \sqrt{\frac{2}{3}} \cdot \sqrt{(M_{rd})^2 + (M_{rq})^2}$$

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W \cdot \begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} + \frac{-1}{C_r} \cdot \begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix} \cdot I_{dc} + \frac{1}{C_r} \cdot \begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix}$$

$$\phi_0 = \operatorname{atan}\left(\frac{I_{sq}}{I_{sd}}\right)$$

$$P_{dc\_0} = R_{dc} \cdot I_{dc}^2$$

$$\begin{pmatrix} I_{sd} & I_{sq} & V_{rd} & V_{rq} & I_{dc} & M_{rd} & M_{rq} & C_r \end{pmatrix} := \operatorname{Find}(I_{sd}, I_{sq}, V_{rd}, V_{rq}, I_{dc}, M_{rd}, M_{rq}, C_r)^T$$

**Se encuentra el Capacitor AC apropiado**

$m_{rdq}(t) := \begin{pmatrix} M_{rd} & M_{rq} \end{pmatrix}^T$

$$\begin{pmatrix} I_{sd} & I_{sq} & V_{rd} & V_{rq} & I_{dc} & M_{rd} & M_{rq} & C_r \end{pmatrix} = \begin{pmatrix} 10.914 & -6.301 & 310.749 & -96.562 & 20 & 0.413 & -0.741 & 8.727 \times 10^{-5} \end{pmatrix}$$

Ángulo de Corriente

$\phi := \operatorname{atan}\left(\frac{I_{sq}}{I_{sd}}\right)$

$\phi \cdot \frac{180}{\pi} = -30$

Potencia en la Carga

$P_{dc\_0} := R_{dc} \cdot I_{dc}^2$

$P_{dc\_0} \cdot 10^{-3} = 4$

Ampl. Mod. en abc

$M_r := \frac{2}{\sqrt{3}} \cdot \sqrt{\frac{2}{3}} \cdot \sqrt{(M_{rd})^2 + (M_{rq})^2}$

$M_r = 0.8$

Filtro AC

$L_s \cdot 10^3 = 30$

$C_r \cdot 10^6 = 87.273$

Frec. de Resonancia:

$\omega_{rn} := \left(\omega_s \cdot \sqrt{L_s \cdot C_r}\right)^{-1}$

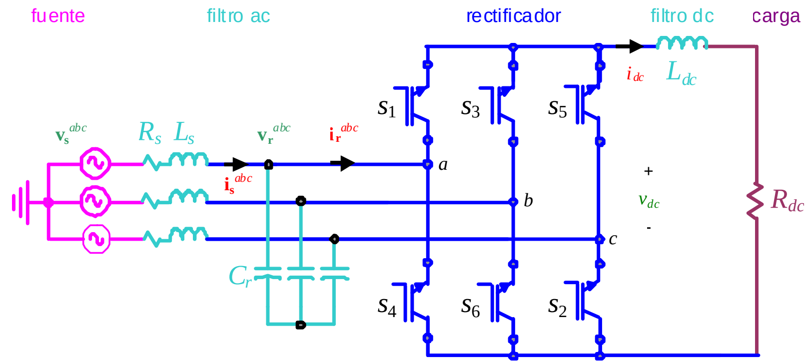
$\omega_{rn} = 1.967$

**¿ Epecificar una frec. de resonancia ?**

# Punto de operación del Rectificador de Corriente Trifásico en dq0



**Problema** Encontrar un punto de operación




$\phi_0 \cdot \frac{180}{\pi} = -30$ $\quad P_{dc\_0} = 4 \times 10^3$ $\quad M_r = 0.8$ $\quad \omega_{rn} := 3$

c.i. para Given/Find que deben ser igual en número al número de incógnitas

$\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} = \begin{pmatrix} 10.914 \\ -6.301 \end{pmatrix}$ $\quad \begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} = \begin{pmatrix} 310.749 \\ -96.562 \end{pmatrix}$ $\quad \begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix} = \begin{pmatrix} 0.413 \\ -0.741 \end{pmatrix}$ $\quad I_{dc} = 20$

Given

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W \cdot \begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} + \frac{-R_s}{L_s} \cdot \begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} - \frac{1}{L_s} \cdot \begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} + \frac{1}{L_s} \cdot \begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix}$$

$$0 = \frac{-R_{dc}}{L_{dc}} \cdot I_{dc} + \frac{1}{L_{dc}} \cdot \begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix}^T \cdot \begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}$$

$$M_r = \frac{2}{\sqrt{3}} \cdot \sqrt{\frac{2}{3}} \cdot \sqrt{(M_{rd})^2 + (M_{rq})^2}$$

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W \cdot \begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} + \frac{-1}{C_r} \cdot \begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix} \cdot I_{dc} + \frac{1}{C_r} \cdot \begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix}$$

$$\phi_0 = \operatorname{atan}\left(\frac{I_{sq}}{I_{sd}}\right) \qquad P_{dc\_0} = R_{dc} \cdot I_{dc}^2 \qquad \omega_{rn} = \left(\omega_s \cdot \sqrt{L_s \cdot C_r}\right)^{-1}$$

$$\left(I_{sd}\ I_{sq}\ V_{rd}\ V_{rq}\ I_{dc}\ M_{rd}\ M_{rq}\ C_r\ L_s\right) := \operatorname{Find}\left(I_{sd}, I_{sq}, V_{rd}, V_{rq}, I_{dc}, M_{rd}, M_{rq}, C_r, L_s\right)^T$$

**Se encuentra el Inductor AC apropiado**

$m_{rdq}(t) := \left(M_{rd}\ \ M_{rq}\right)^T$

$$\left(I_{sd}\ I_{sq}\ V_{rd}\ V_{rq}\ I_{dc}\ M_{rd}\ M_{rq}\ C_r\ L_s\right) = \left(10.914\ \ -6.301\ \ 338.629\ \ -48.273\ \ 20\ \ 0.492\ \ -0.691\ \ 7.073 \times 10^{-5}\ \ 0.016\right)$$

Ángulo de Corriente

$\phi := \operatorname{atan}\left(\frac{I_{sq}}{I_{sd}}\right)$

$\phi \cdot \frac{180}{\pi} = -30$

Potencia en la Carga

$P_{dc\_0} := R_{dc} \cdot I_{dc}^2$

$P_{dc\_0} \cdot 10^{-3} = 4$

Ampl. Mod. en abc

$M_r := \frac{2}{\sqrt{3}} \cdot \sqrt{\frac{2}{3}} \cdot \sqrt{(M_{rd})^2 + (M_{rq})^2}$

$M_r = 0.8$

Filtro AC

$L_s \cdot 10^3 = 15.917$

$C_r \cdot 10^6 = 70.73$

Frec. de Resonancia:

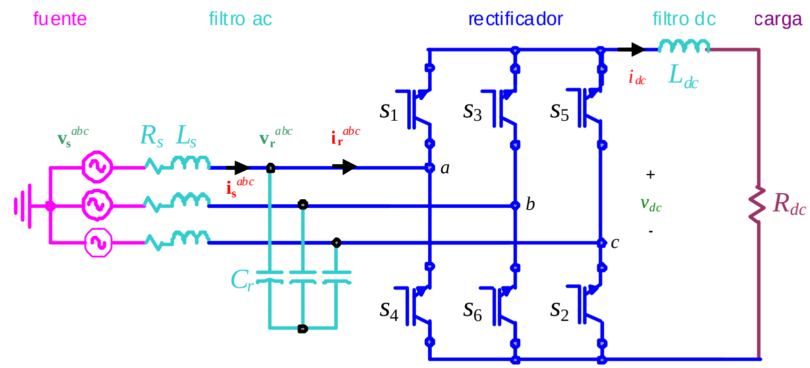
$\omega_{rn} := \left(\omega_s \cdot \sqrt{L_s \cdot C_r}\right)^{-1}$

$\omega_{rn} = 3$

# Punto de operación del Rectificador de Corriente Trifásico en abc



**Problema** Estudiar el modelo del rectificador de corriente con Modulación SPWM.




La moduladora es, $m_r(t) := T_{abc\_dq0}(t)^T \cdot \begin{pmatrix} M_{rd} \\ M_{rq} \\ 0 \end{pmatrix}$

$m_a(t) := \frac{2}{\sqrt{3}} \cdot m_r(t)_1$ $m_b(t) := \frac{2}{\sqrt{3}} \cdot m_r(t)_2$ $m_c(t) := \frac{2}{\sqrt{3}} \cdot m_r(t)_3$

$M := \sqrt{\frac{2}{3}} \cdot \sqrt{m_a(0)^2 + m_b(0)^2 + m_c(0)^2}$ $f_M := \operatorname{atan}\left(\frac{M_{rq}}{M_{rd}}\right)$

$M = 0.8$ $f_M \cdot \frac{180}{\pi} = -54.556$

$R_s = 1$ $C_r \cdot 10^6 = 70.73$

$L_s \cdot 10^3 = 15.917$ $L_{dc} \cdot 10^3 = 30$ $R_{dc} = 10$

La triangular es, $f_{n\_tr} := 15$ $per := 1$ $tri(t) := \frac{2}{\pi} \cdot \operatorname{asin}\left(\sin\left(f_{n\_tr} \cdot \omega_s \cdot t + f_M \cdot f_{n\_tr} - \frac{\pi}{2}\right)\right)$

$m_{ax}(t) := (m_a(t) - m_b(t)) \cdot (\sqrt{3})^{-1}$ $s_x(t) := \text{if}(m_{ax}(t) > tri(t), 1, 0)$ $s_{xn}(t) := \text{if}(s_x(t) = 1, 0, 1)$

$m_{bx}(t) := (m_b(t) - m_c(t)) \cdot (\sqrt{3})^{-1}$ $s_y(t) := \text{if}(m_{bx}(t) > tri(t), 1, 0)$ $s_{yn}(t) := \text{if}(s_y(t) = 1, 0, 1)$

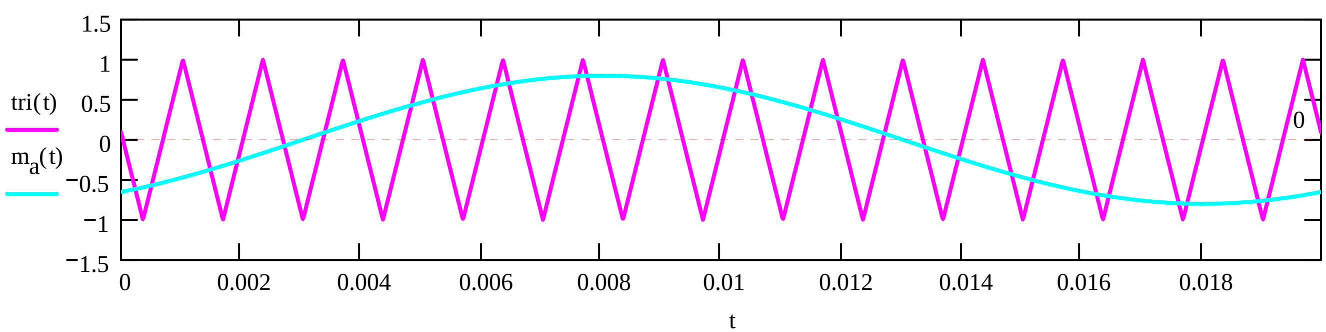
$m_{cx}(t) := (m_c(t) - m_a(t)) \cdot (\sqrt{3})^{-1}$ $s_z(t) := \text{if}(m_{cx}(t) > tri(t), 1, 0)$ $s_{zn}(t) := \text{if}(s_z(t) = 1, 0, 1)$

$s_1(t) := s_x(t) \cdot s_{zn}(t)$ $s_4(t) := s_z(t) \cdot s_{xn}(t)$ $s_a(t) := s_1(t) - s_4(t)$

$s_3(t) := s_y(t) \cdot s_{xn}(t)$ $s_6(t) := s_x(t) \cdot s_{yn}(t)$ $s_b(t) := s_3(t) - s_6(t)$

$s_5(t) := s_z(t) \cdot s_{yn}(t)$ $s_2(t) := s_y(t) \cdot s_{zn}(t)$ $s_c(t) := s_5(t) - s_2(t)$

$s_r(t) := \begin{pmatrix} s_a(t) \\ s_b(t) \\ s_c(t) \end{pmatrix}$ $v_s(t) := T_{abc\_dq0}(t)^T \cdot \begin{pmatrix} V_{sd} \\ V_{sq} \\ 0 \end{pmatrix}$



**Simulación** $t_f := 0.02$ $n_f := 2048$ $n := 1 .. n_f$ $t := 0, \frac{t_f}{n_f} .. t_f$

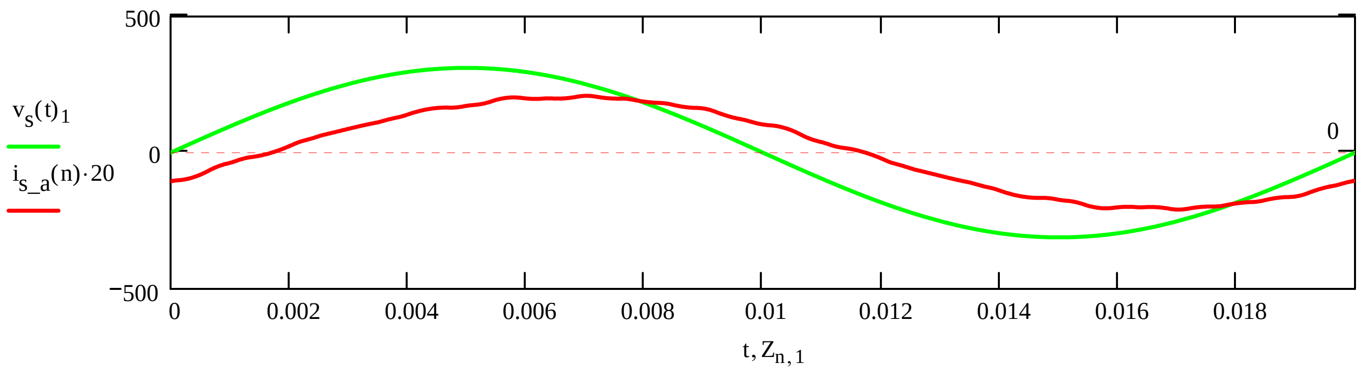
$$D(t,x) := \text{stack}\left(\frac{-R_s}{L_s}\cdot\begin{pmatrix}x_1 & x_2 & x_3\end{pmatrix}^T - \frac{1}{L_s}\cdot\begin{pmatrix}x_4 & x_5 & x_6\end{pmatrix}^T + \frac{1}{L_s}\cdot v_s(t), \frac{-1}{C_r}\cdot s_r(t)\cdot x_7 + \frac{1}{C_r}\cdot\begin{pmatrix}x_1 & x_2 & x_3\end{pmatrix}^T, \frac{-R_{dc}}{L_{dc}}\cdot x_7 + \frac{1}{L_{dc}}\cdot\begin{pmatrix}x_4 & x_5 & x_6\end{pmatrix}^T\cdot s_r(t)\right)$$

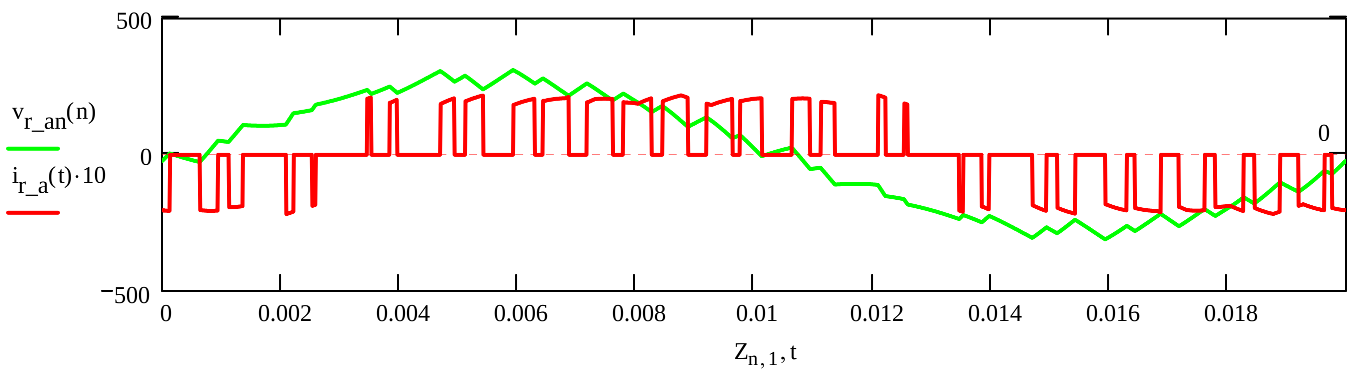
$$CI := \begin{pmatrix}-5.208 & -4.926 & 10.134 & -20.061 & -230.723 & 250.783 & 20.47\end{pmatrix}^T \quad Z := \text{rkfixed}(CI, 0, t_f, n_f, D)$$

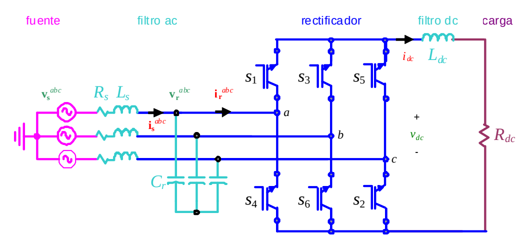
$$CI := \begin{pmatrix}Z_{n_f,2} & Z_{n_f,3} & Z_{n_f,4} & Z_{n_f,5} & Z_{n_f,6} & Z_{n_f,7} & Z_{n_f,8}\end{pmatrix}^T \quad Z := \text{rkfixed}(CI, 0, t_f, n_f, D) \quad i_{s\_a}(n) := Z_{n,2} \quad i_{s\_b}(n) := Z_{n,3} \quad i_{s\_c}(n) := Z_{n,4}$$

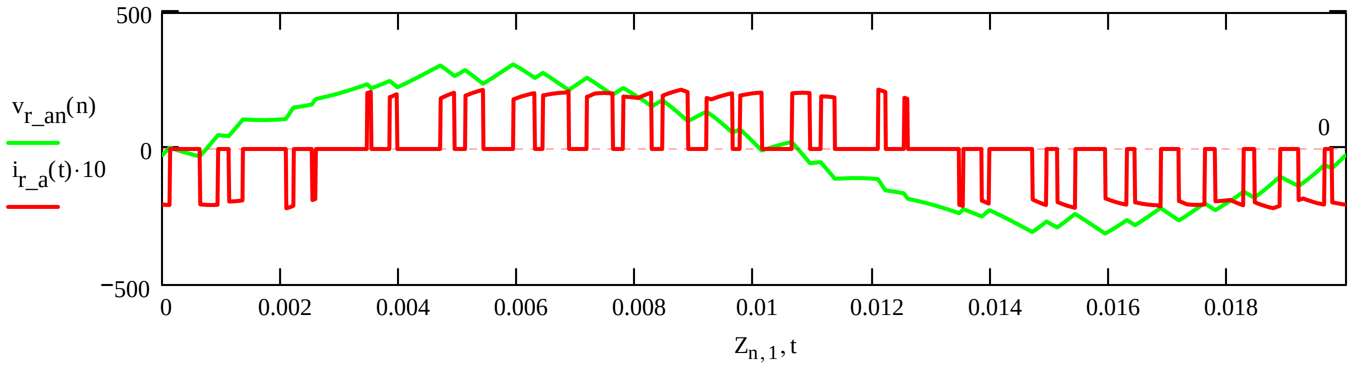
$$i_{dc}(n) := Z_{n,8} \quad i_{r\_a}(t) := \left(s_r(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_1 \quad i_{r\_b}(t) := \left(s_r(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_2 \quad i_{r\_c}(t) := \left(s_r(t)\cdot i_{dc}\left(t\cdot\frac{n_f}{t_f}\right)\right)_3 \quad v_{r\_an}(n) := Z_{n,5} \; v_{r\_bn}(n) := Z_{n,6} \; v_{r\_cn}(n) := Z_{n,7}$$

$$v_{dc}(n) := s_r\left(n\cdot\frac{t_f}{n_f}\right)^T\cdot\begin{pmatrix}v_{r\_an}(n) & v_{r\_bn}(n) & v_{r\_cn}(n)\end{pmatrix}^T$$





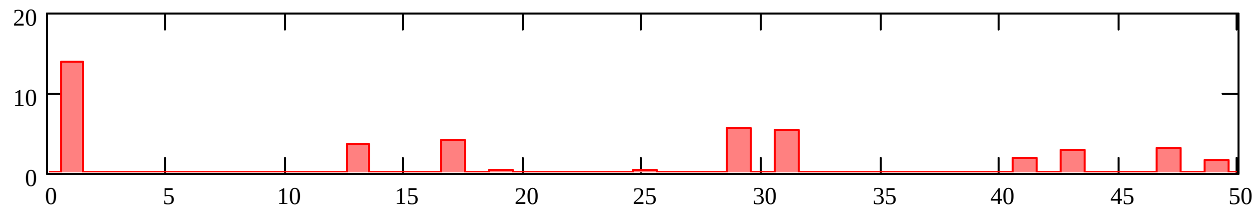

$N := 1024$ $\quad m := 1..N$

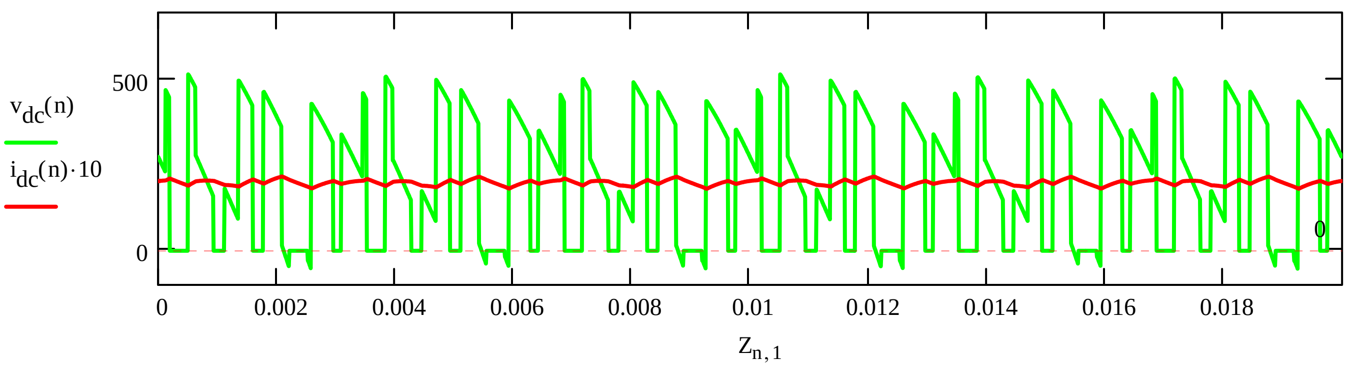
$x_m := i_{r\_a}\left(\frac{m}{N}\cdot t_f\right)$ $\quad xf := FFT(x)$

$xv(m) := if(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(2)| = 13.886$

**FFT de $i_{r\_a}$**




$N := 1024$ $\quad m := 1..N$

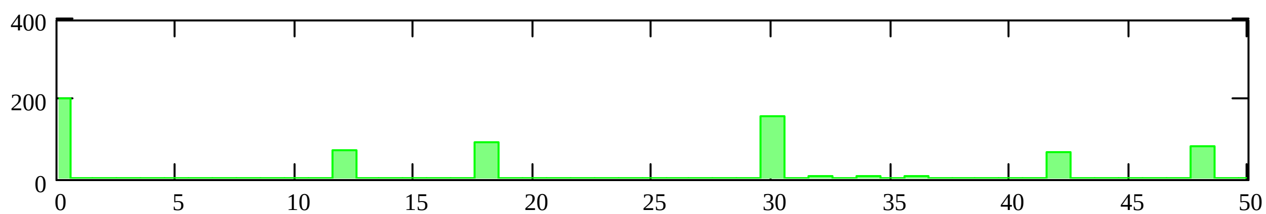
$x_m := v_{dc}\left(\frac{m}{N}\cdot n_f\right)$ $\quad xf := FFT(x)$

$xv(m) := if(m = 1, 1, 2)\cdot xf_{m\cdot per}$

$|xv(1)| = 203.235$ $\quad V_{dc} := |xv(1)|$

$P_o := \frac{V_{dc}^2}{R_{dc}}$ $\quad P_o = 4.13\times 10^3$

**FFT de $v_{dc}$**




**El voltaje DC no tiene segunda armónica. Sólo armónicas de conmutación.**

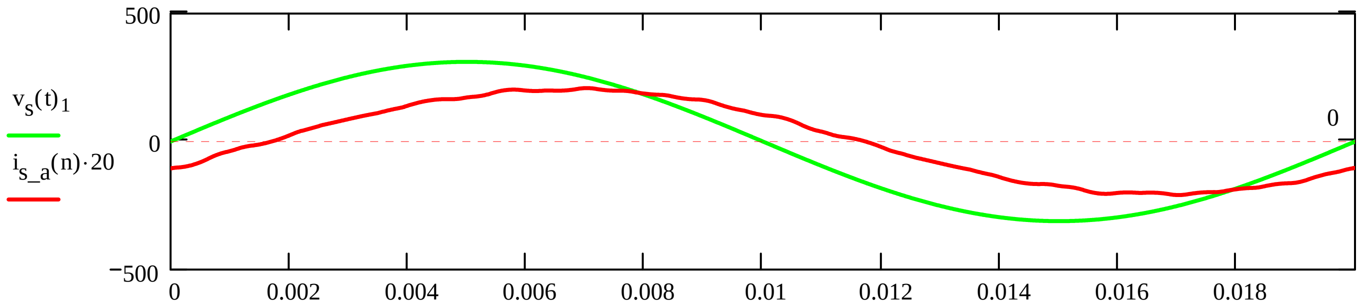
$v_{abc}(t) := v_s(t)$ $\quad i_{abc}(t) := \left( i_{s\_a}\left(t\cdot\frac{n_f}{t_f}\right) \;\; i_{s\_b}\left(t\cdot\frac{n_f}{t_f}\right) \;\; i_{s\_c}\left(t\cdot\frac{n_f}{t_f}\right) \right)^T$ $\quad p_{abc}(t) := v_{abc}(t)^T \cdot i_{abc}(t)$ $\quad q_{abc}(t) := v_{abc}(t) \times i_{abc}(t)$

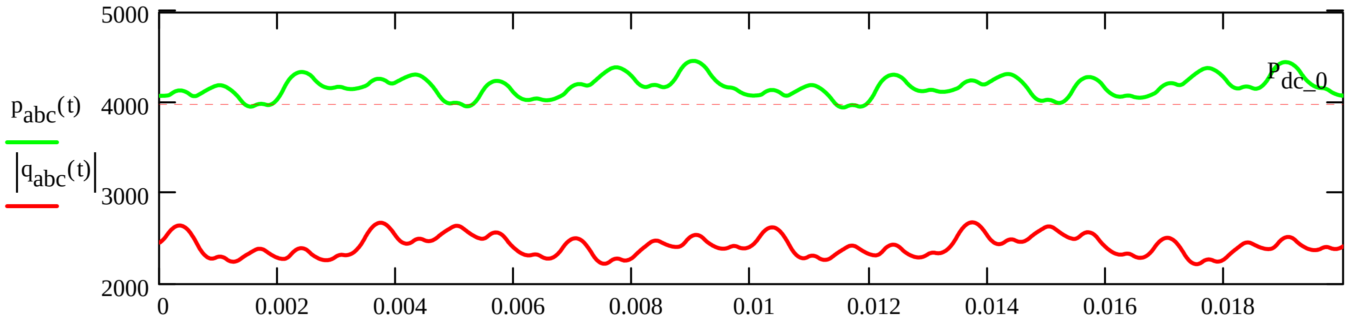


$$s_{abc}(t) := \sqrt{\left(\left|v_{abc}(t)\right|\right)^2 \cdot \left(\left|i_{abc}(t)\right|\right)^2}$$

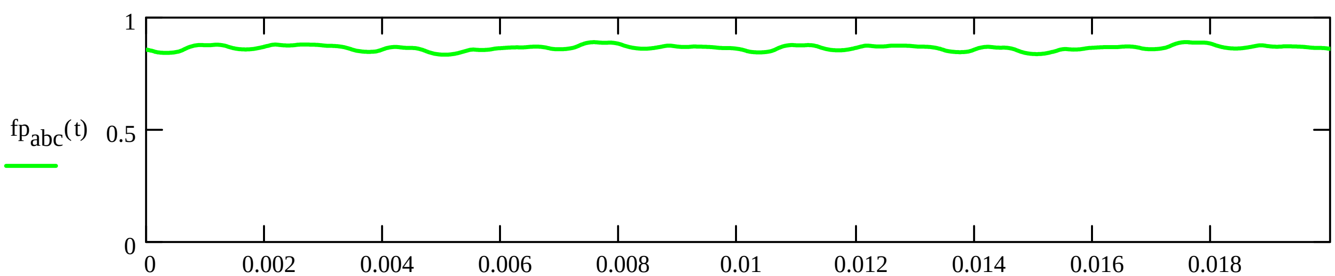
$$fp_{abc}(t) := \frac{p_{abc}(t)}{s_{abc}(t)}$$

$$\phi(t) := \operatorname{atan}\left[\frac{\left(T_{abc\_dq0}(t)\cdot i_{abc}(t)\right)_2}{\left(T_{abc\_dq0}(t)\cdot i_{abc}(t)\right)_1}\right]$$

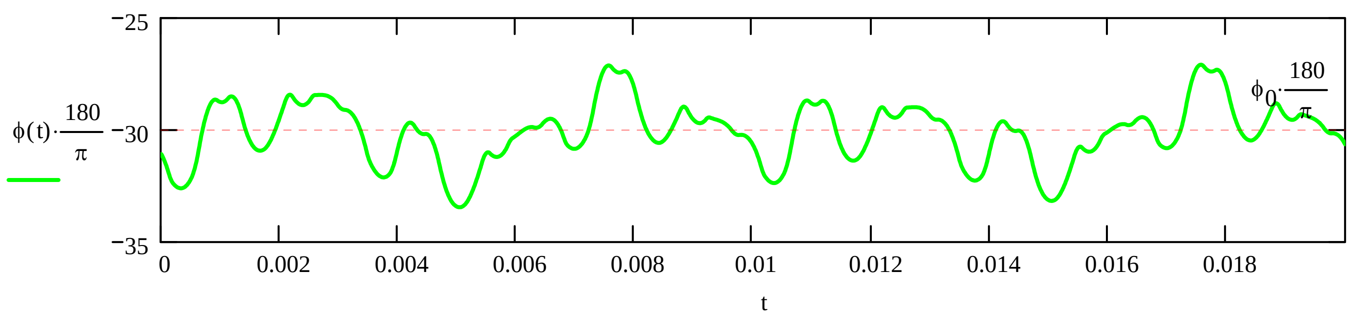


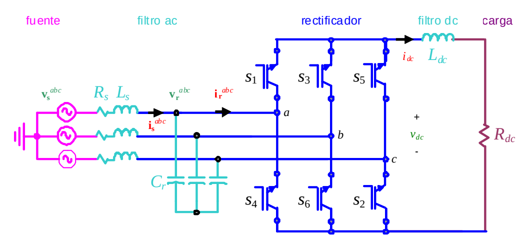




El sistema si está en S.S.



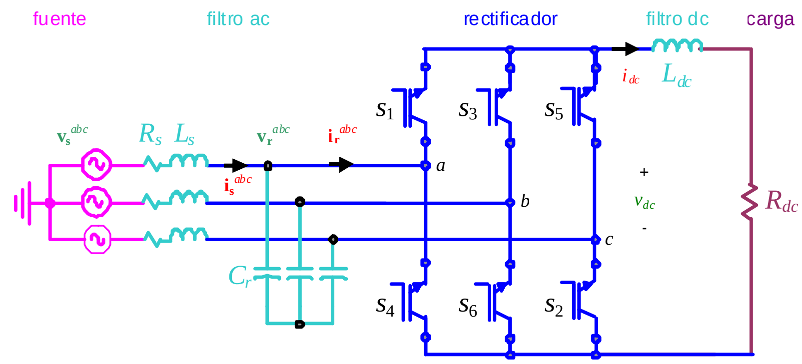

¿ Qué rangos puede alcanzar el sistema ?... **La Región de Operación** entrega esta respuesta.



**Problema** Estudiar el modelo promedio en dq0 del rectificador de voltaje.

$t := 0$




$$m_{r\_abc}(M, f_M) := \frac{\sqrt{3}}{2} \cdot \begin{pmatrix} M \cdot \sin\left(\omega_s \cdot t + f_M - \frac{0 \cdot \pi}{3}\right) \\ M \cdot \sin\left(\omega_s \cdot t + f_M - \frac{2 \cdot \pi}{3}\right) \\ M \cdot \sin\left(\omega_s \cdot t + f_M - \frac{4 \cdot \pi}{3}\right) \end{pmatrix}$$

$$m_{r\_dq0}(M, f_M) := T_{abc\_dq0}(t) \cdot m_{r\_abc}(M, f_M)$$

$X_a(M, f_M) := m_{r\_abc}(M, f_M)_1$

$Y_b(M, f_M) := m_{r\_abc}(M, f_M)_2$

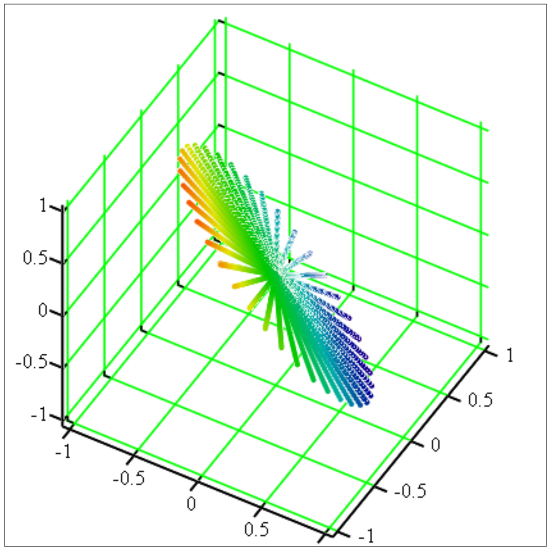
$Z_c(M, f_M) := m_{r\_abc}(M, f_M)_3$

$X_d(M, f_M) := m_{r\_dq0}(M, f_M)_1$

$Y_q(M, f_M) := m_{r\_dq0}(M, f_M)_2$

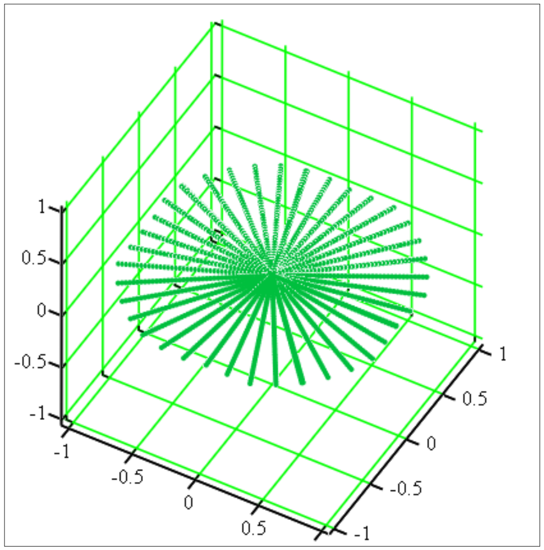
$Z_0(M, f_M) := m_{r\_dq0}(M, f_M)_3$

Las señales en abc en función de M y $f_M$.



$(X_a, Y_b, Z_c)$

Las señales en dq0 en función de M y $f_M$.

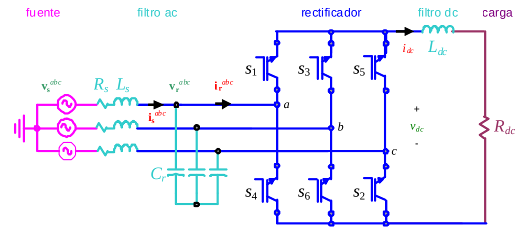


$(X_d, Y_q, Z_0)$

c.i. para Given/Find que deben ser igual en número al número de incógnitas

$\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} := \begin{pmatrix} 10 \\ -10 \end{pmatrix}$ $\begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} := \begin{pmatrix} 100 \\ 0 \end{pmatrix}$ $\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix} := \begin{pmatrix} 0.5 \\ 0. \end{pmatrix}$ $I_{dc} := 20$ $\begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} := \begin{pmatrix} \sqrt{3}\cdot 220 \\ 0 \end{pmatrix}$ $Max := \frac{\sqrt{3}}{2}\cdot\sqrt{\frac{3}{2}}$






Given

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W\cdot\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} + \frac{-R_s}{L_s}\cdot\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} - \frac{1}{L_s}\cdot\begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} + \frac{1}{L_s}\cdot\begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix}$$

$$0 = \frac{-R_{dc}}{L_{dc}}\cdot I_{dc} + \frac{1}{L_{dc}}\cdot\begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix}^T\cdot\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}$$

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = -W\cdot\begin{pmatrix} V_{rd} \\ V_{rq} \end{pmatrix} + \frac{-1}{C_r}\cdot\begin{pmatrix} M_{rd} \\ M_{rq} \end{pmatrix}\cdot I_{dc} + \frac{1}{C_r}\cdot\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix}$$

$Sol(M_{rd}, M_{rq}) := Find(I_{sd}, I_{sq}, V_{rd}, V_{rq}, I_{dc})$

**Se graficará para $M_{rd}$ y $M_{rq}$ en el rango -Max a Max.**

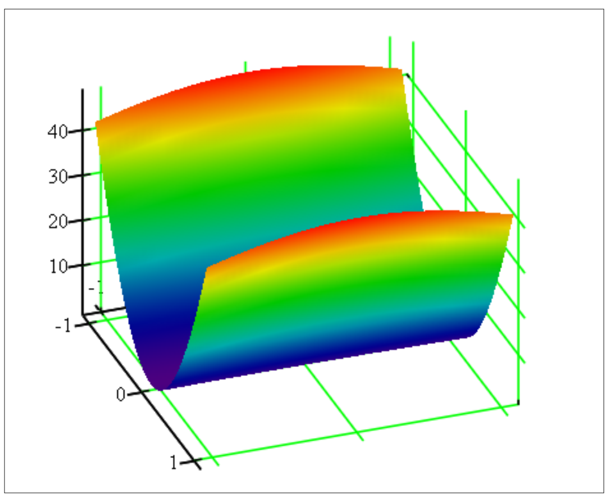
$me := 40$ $mi_1 := -Max$ $ma_1 := Max$ $mi_2 := -Max$ $ma_2 := Max$

**A graficar $I_{sd}$, $I_{sq}$ y $I_{dc}$**

$I_{sd}(x_d, x_q) := Sol(x_d, x_q)_1$ $I_{sq}(x_d, x_q) := Sol(x_d, x_q)_2$ $I_{dc}(x_d, x_q) := Sol(x_d, x_q)_5$

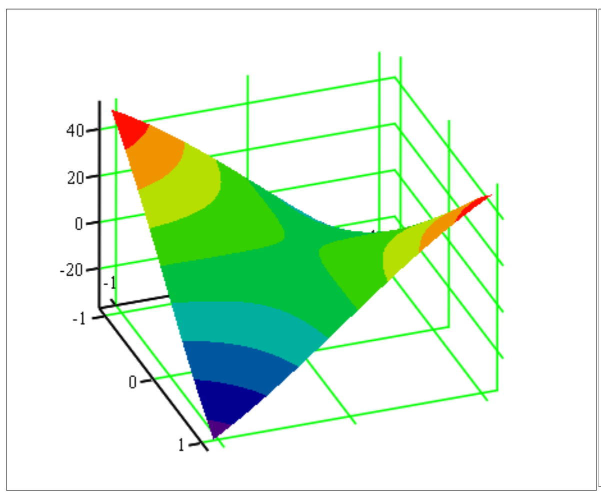
$S_{I\_sd} := CreateMesh(I_{sd}, mi_2, ma_2, mi_1, ma_1, me)$ $S_{I\_sq} := CreateMesh(I_{sq}, mi_2, ma_2, mi_1, ma_1, me)$ $S_{I\_dc} := CreateMesh(I_{dc}, mi_2, ma_2, mi_1, ma_1, me)$

**Corriente $I_{sd}$**



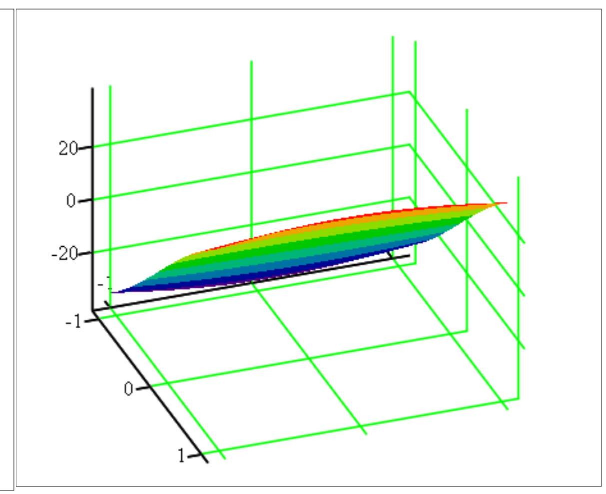

$S_{I\_sd}$

**Corriente $I_{sq}$**




$S_{I\_sq}$

**Corriente $I_{dc}$**

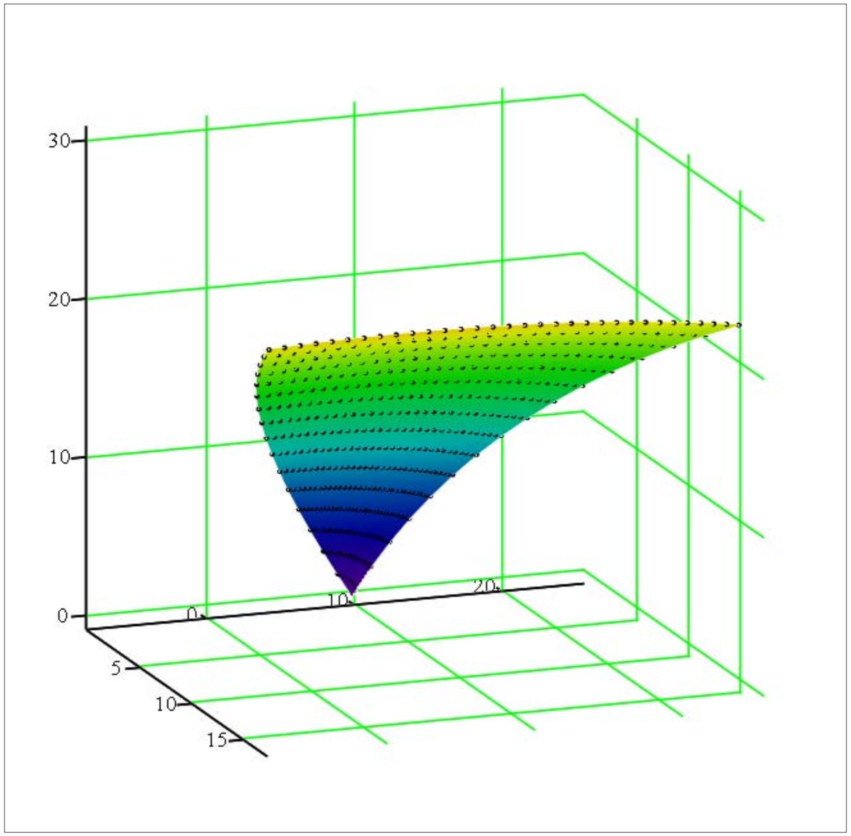



$S_{I\_dc}$

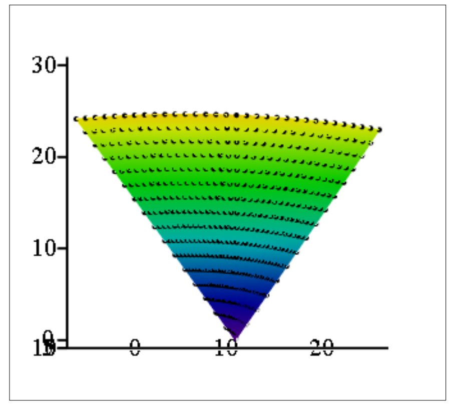
La corriente $I_{dc}$ negativa no es opción, por switches unidireccionales de la topología.

Hay dos entradas $M_{rd}$ y $M_{rq}$ y hay tres variables de estado.
Las potenciales salidas podrían ser $I_{sd}$ e $I_{sq}$, $I_{sd}$ e $I_{dc}$, $I_{dc}$ e $I_{sq}$.

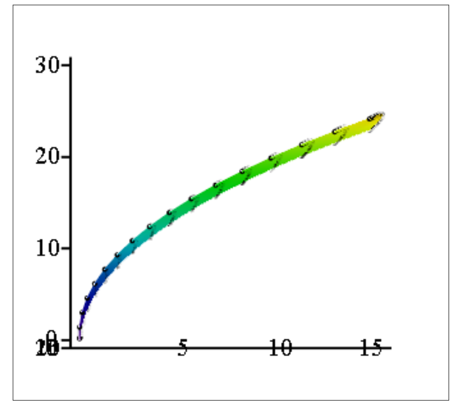
Es posible controlar $I_{sd}$ e $I_{sq}$, $I_{dc}$ e $I_{sq}$, pero **NO** se puede controlar $I_{sd}$ e $I_{dc}$ por el rango mínimo.



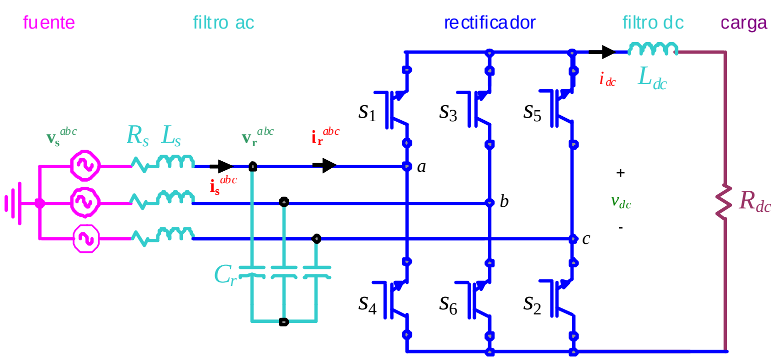

$(I_{sd}, I_{sq}, I_{dc})$

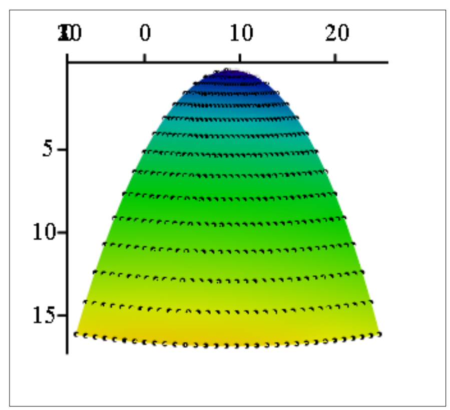



$(I_{sd}, I_{sq}, I_{dc})$




$(I_{sd}, I_{sq}, I_{dc})$




$(I_{sd}, I_{sq}, I_{dc})$