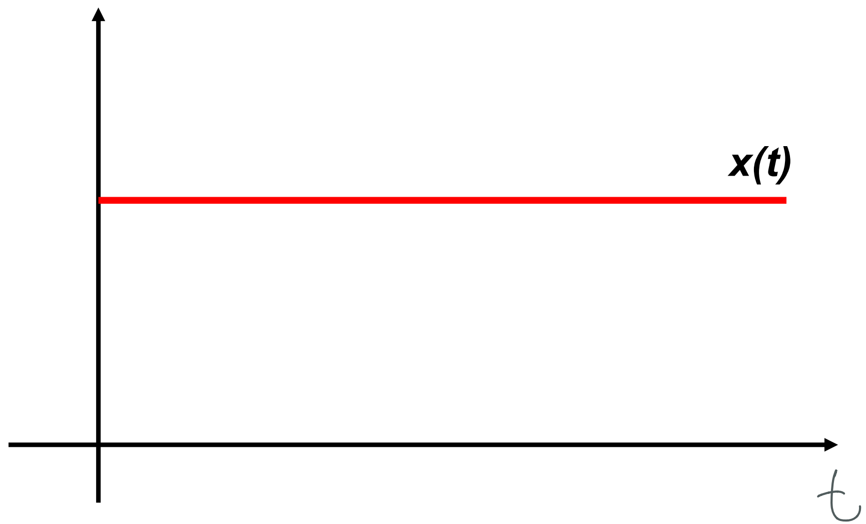
Repaso conceptos básicos y análisis

Régimen Permanente

Sistemas con excitaciones continuas

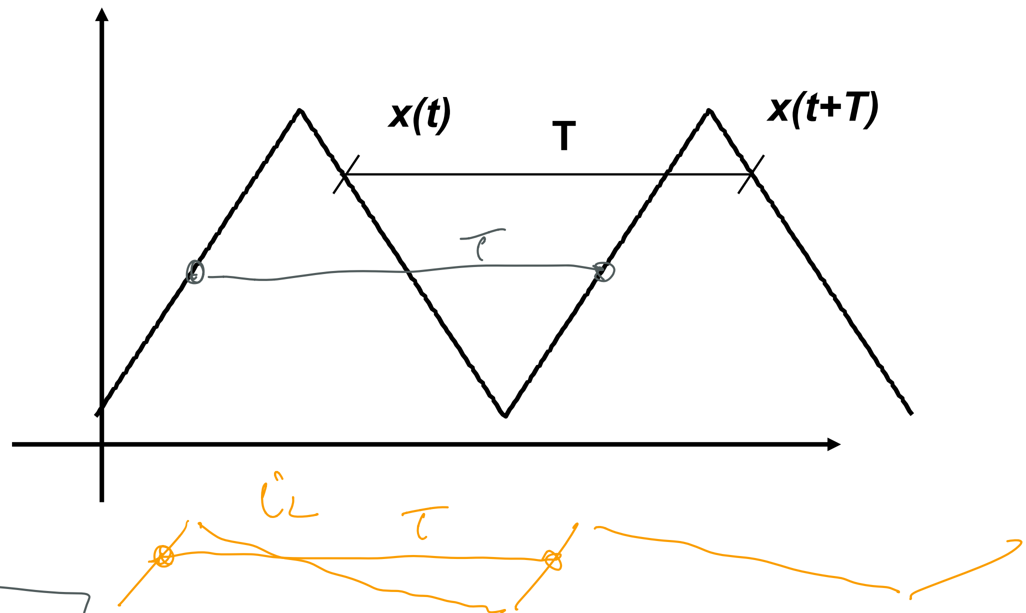
$$\frac{dx}{dt} = 0$$



Régimen Permanente

Sistemas con excitación periódica

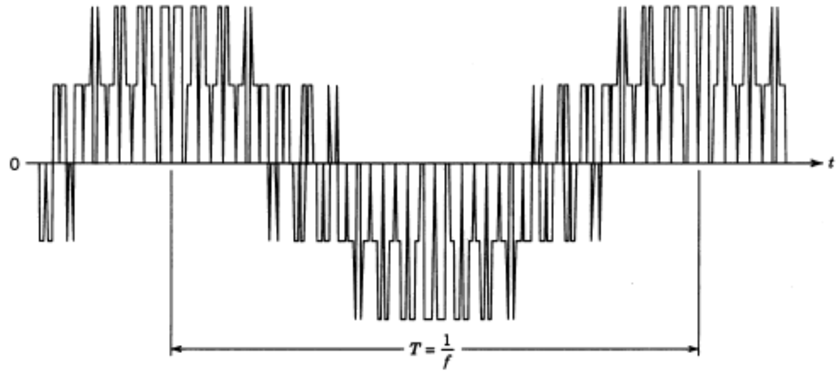
$$\cancel{\frac{dx}{dt}=0}$$



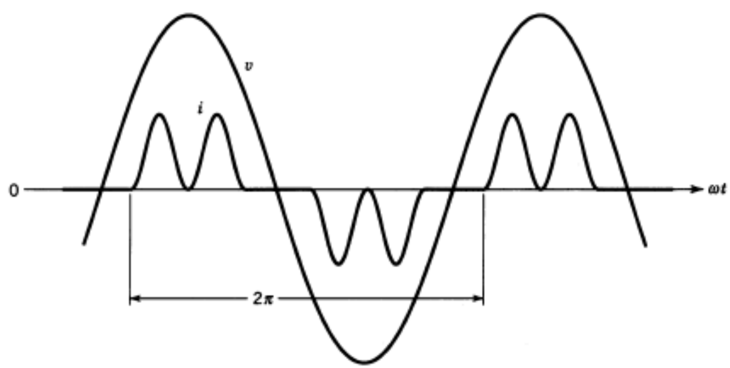
$$\boxed{x(t+T)=x(t)}$$

Régimen Permanente

Ejemplo en electrónica de potencia



(a)



Condición de régimen permanente

Balance de flujo en la bobina

$E_L = \frac{1}{2} L i^2$

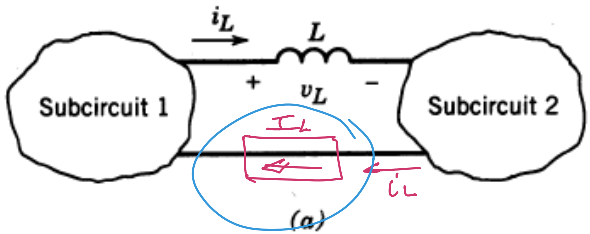
$\boxed{\bar{V}_L = 0}$

$I_L = cte$

$\uparrow$

$\Delta i \to 0$

$\Delta i = \frac{v}{L} \cdot \Delta t$



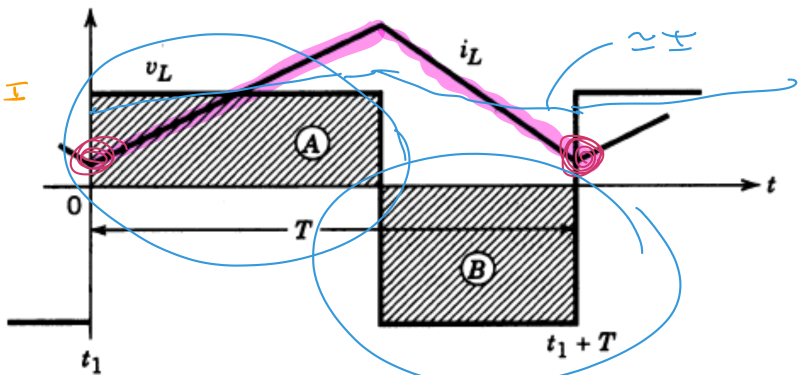
$v = L \frac{di}{dt}$

$\Delta i = \frac{v}{L} \Delta t$

$v = L \frac{di}{dt}$

$L \uparrow\uparrow \Rightarrow \Delta i \to 0 \Rightarrow$ I

$\cancel{v(t) = 0 \;!!}$



Balance de carga en el condensador

$$E = \frac{1}{2} C v^2$$

Rég Perm: $\boxed{\overline{i_c} = 0}$

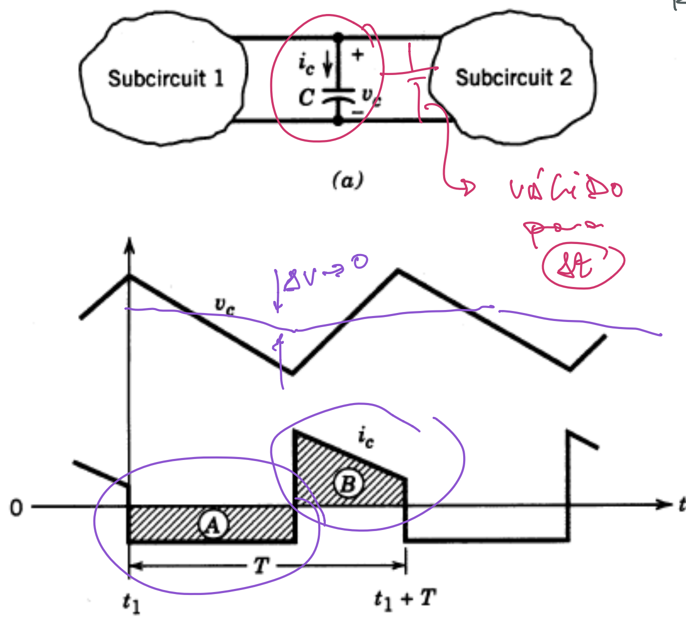
$$i = C \frac{dv}{dt}$$

si $C \uparrow\uparrow \Rightarrow \Delta v \to 0 \Rightarrow$ v_c

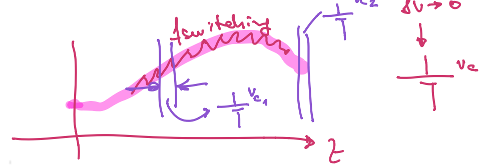
$\cancel{i(t) = 0}$

$$i = C\frac{dv}{dt} \Rightarrow \Delta v = \frac{i}{C} \cdot \Delta t$$

$\Delta v \to 0$



válido para Δt



Valor medio y valor eficaz

Valor medio

$$\langle x\rangle = \frac{1}{T}\int_T x(t)\,dt$$

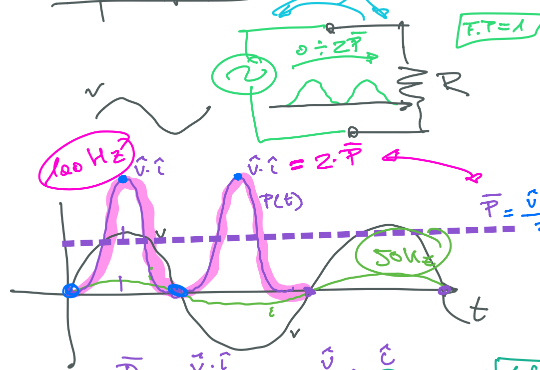
$\hat{v}\cdot \text{sen}\,\omega t$

$\hat{i}\cdot \text{sen}\,\omega t$

$\hat{v}\cdot\hat{i}\cdot \text{sen}^2\omega t$

$\hat{v}\cdot\hat{i}\cdot \frac{1-\cos 2\omega t}{2}$

Ejemplo:



$\bar{P} = \frac{\hat{v}\cdot\hat{i}}{2}$

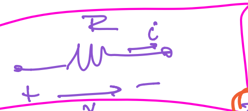
$\bar{P} = \frac{\hat{v}\cdot\hat{i}}{2} \approx \frac{\hat{v}}{\sqrt{2}}\cdot\frac{\hat{i}}{\sqrt{2}}$

$\sqrt{\frac{1}{T}\int x^2\,dt}$

$v_{ef} \cdot i_{ef}$

Valor eficaz

$$\boxed{x_{ef} = \sqrt{\frac{1}{T}\int_T x^2\,dt}}$$



$P(t) = v(t)\cdot i(t) = i^2(t)\cdot R$

$\boxed{\bar{P}} = \frac{1}{T}\int_T P(t)\,dt = R\cdot\frac{1}{T}\int i^2\,dt = i_{ef}^2$

$\boxed{\bar{P} = v_{ef}\cdot i_{ef}}$ ojo!!

$\varphi = 0$

$\boxed{S = V_{ef}\cdot i_{ef}}$ POTENCIA APARENTE

$\boxed{P = V_{ef(1)}\cdot i_{ef(1)}\cdot\cos\varphi}$

PRIMER ARMÓNICO

FACTOR de POTENCIA

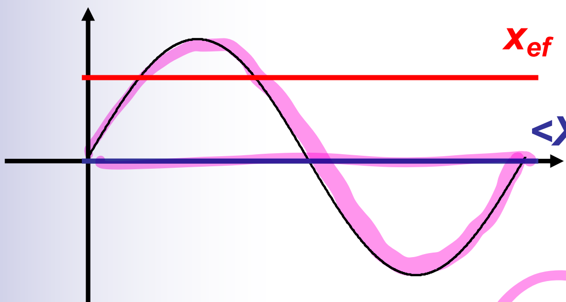
$\boxed{P = \sum V_{j\,ef}\cdot i_{j\,ef}\cdot\cos\varphi_j}$

j ARMÓNICOS

desfase

Valor medio y valor eficaz

Ejemplos

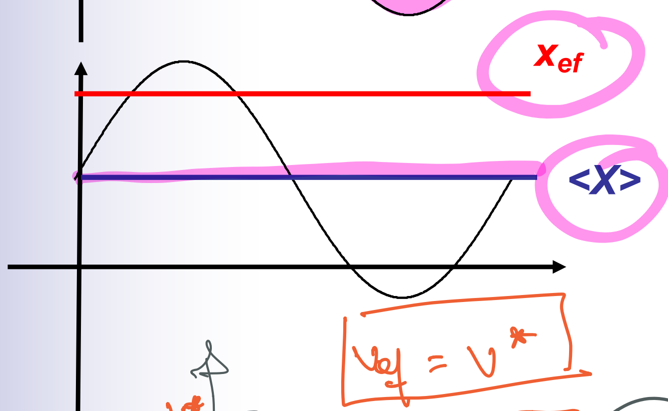


$x_{ef} \neq 0 \Rightarrow P = \frac{V_{ef}^2}{R}$

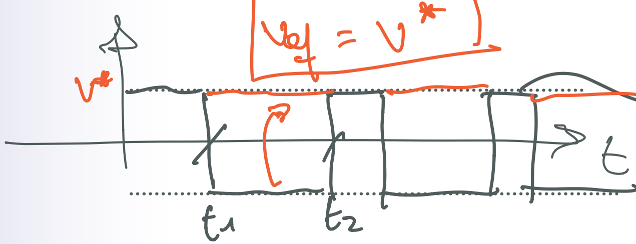
$i_{ef}^2 \cdot R$

$\langle X \rangle = 0$

un cambio de signo NO AFECTA al valor eficaz



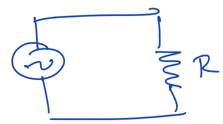
$\boxed{V_{ef} = V^*}$



$v_{ef} = ? = \sqrt{\frac{1}{T}\left(\int_0^{t_1} x_1^2 + \int_{t_1}^{T} x_2^2 \ldots\right)}$

EJEMPLOS

1)



$P = ?$

a) $P(t)$
b) $\bar{P}$
c) F.P
d) DAT

$\hat{P} = 2\bar{P}$

$\bar{P} = \langle P \rangle = \frac{\hat{v}\,\hat{i}}{2} = \frac{\hat{v}}{\sqrt{2}} \cdot \frac{\hat{i}}{\sqrt{2}}$

ojo!

Senoidal Armónico 1.

$\cos\varphi = 1 \Rightarrow \boxed{FP = 1}$

$\varphi = 0°$

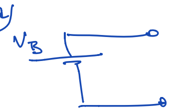
$\boxed{DAT = 0}$

PÉRDIDAS

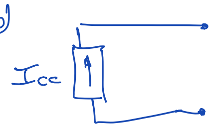
Disipación de POTENCIA innecesaria.

2) Potencia en una fuente de continua.

a)



b)

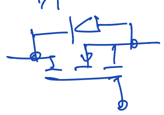


3) Pérdidas en conducción.

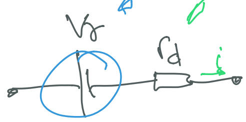
a)

$P_{cond\_D} = ?$

b)

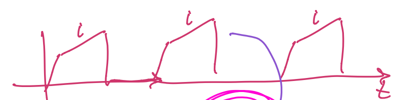


$P_{cond\_MOS} = ?$



$\boxed{P_{rd} = r_d \cdot i_{ef}^2}$

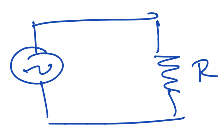
$\boxed{P_{V\gamma} = V_\gamma \cdot \bar{i}}$



$\boxed{P = R_{DSon} \cdot i_{ef}^2}$

EJEMPLOS

1)

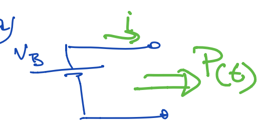


$P = ?$

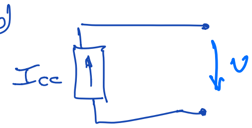
a) $P(t)$
b) $\bar{P}$
c) F.P
d) DAT

2) Potencia en una fuente de contin

a)



b)



$P(t) = V_B \cdot i(t)$

cte

$\bar{P} = \frac{1}{T}\int V_B \cdot i\, dt$

$\boxed{\bar{P} = V_B \cdot \bar{i}}$

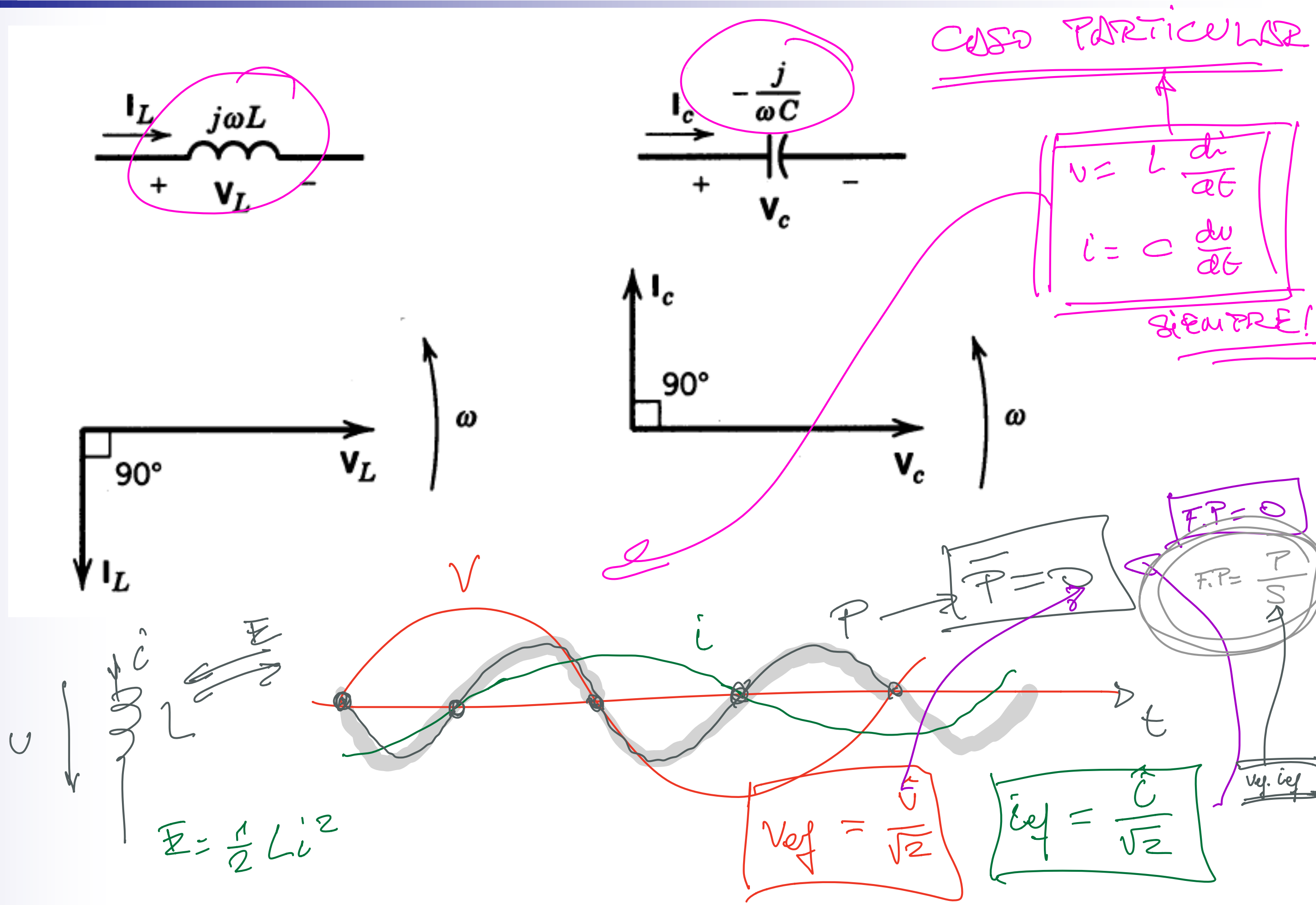
cte

$P(t) = I_{cc} \cdot v(t)$

$\bar{P} = I_{cc} \cdot \bar{v}$

cte

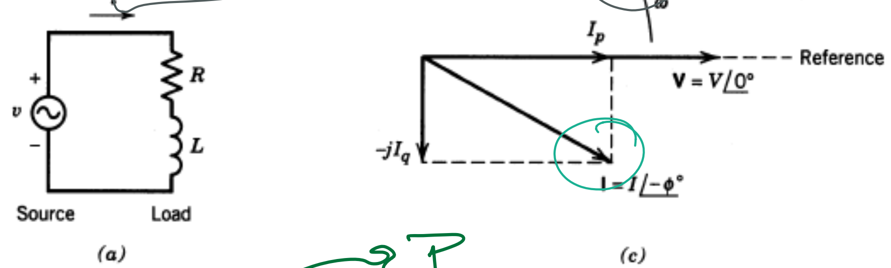
Régimen Sinusoidal Permanente

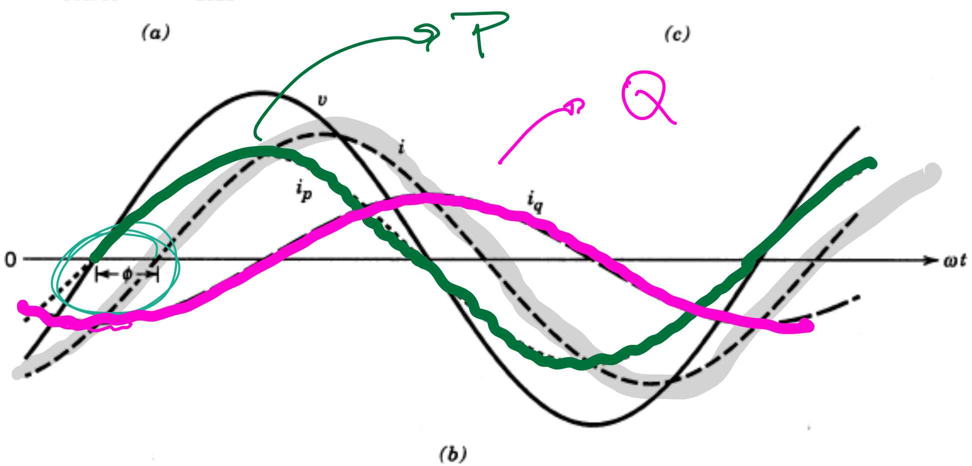


Régimen Sinusoidal Permanente

Potencia, Potencia aparente, potencia reactiva

$$S = V \cdot I^* = P + jQ$$

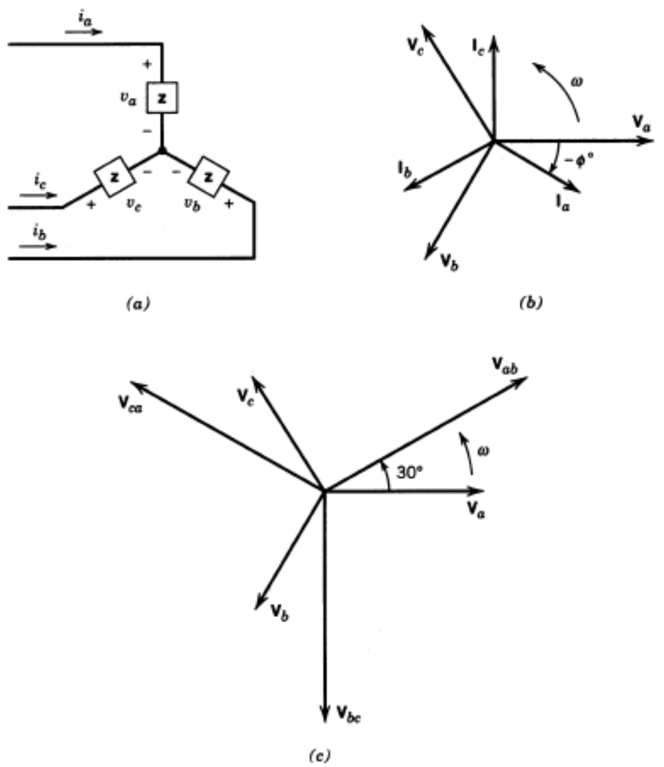




Trabajando con valores eficaces!!

Régimen Sinusoidal Permanente

Circuitos trifásicos

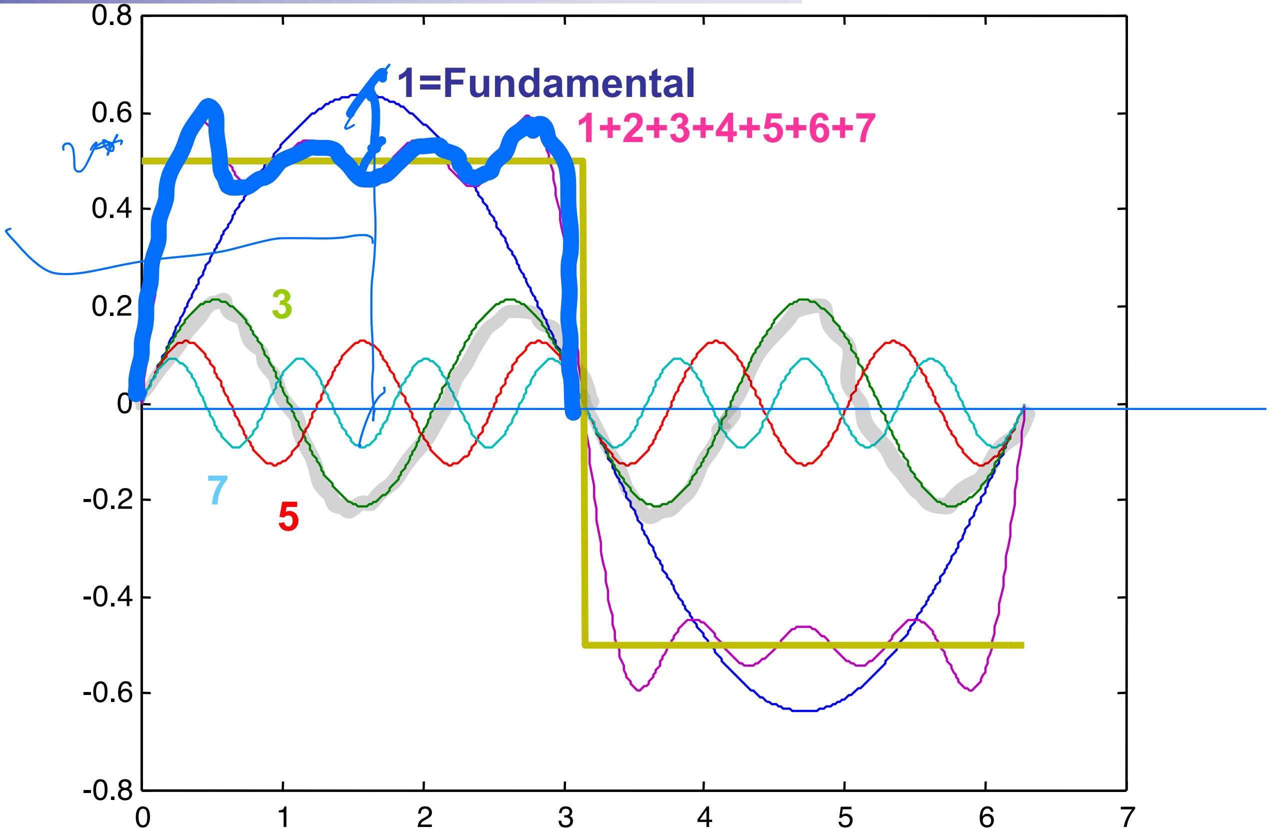


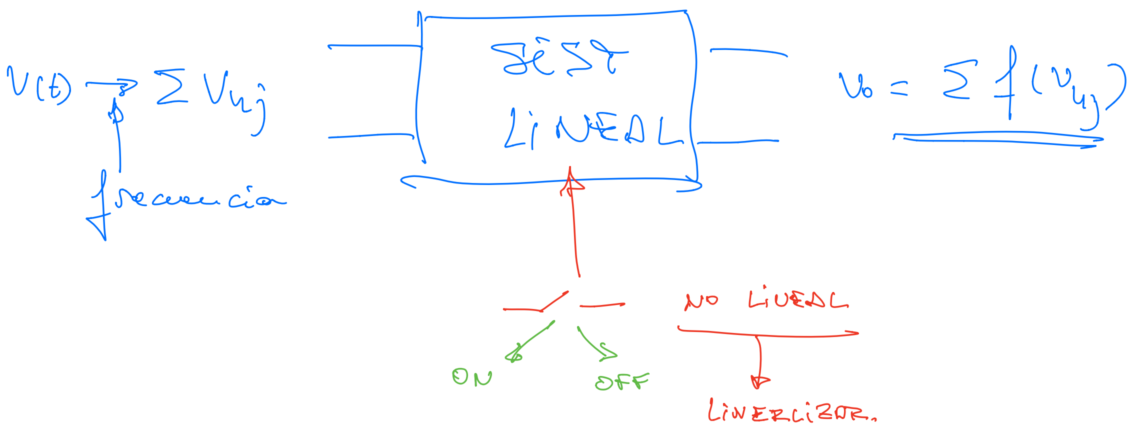
… pero en E. Potencia,
hay dispositivos conmutando,
que producen "armónicos"…

Descomposición en armónicos

Ejemplo

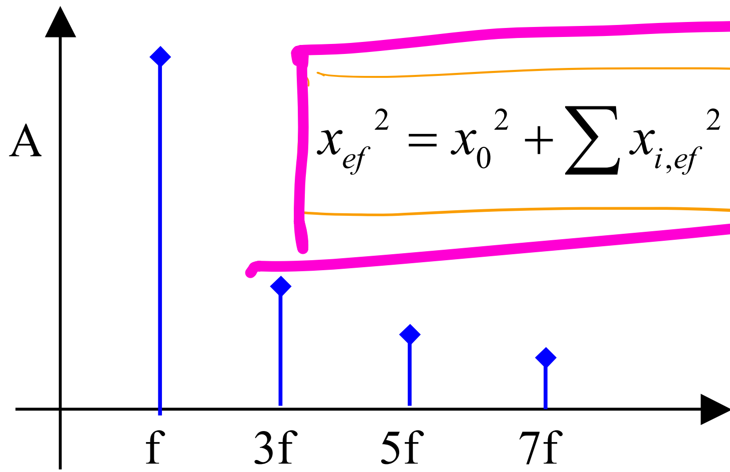
$\frac{4}{\pi} V^*$




$v(t) \rightarrow \sum V_{nj}$
frecuencia
SIST
LINEAL
$v_o = \sum f(v_{nj})$
NO LINEAL
LINEALIZAR.
ON
OFF

Descomposición en armónicos

Ejemplo



$$\boxed{x_{ef}^{\;2} = x_0^{\;2} + \sum x_{i,ef}^{\;2}}$$

$$V_{ef}^2 = V_{1,ef}^2 + \boxed{V_{2,ef}^2 + \cdots +}$$

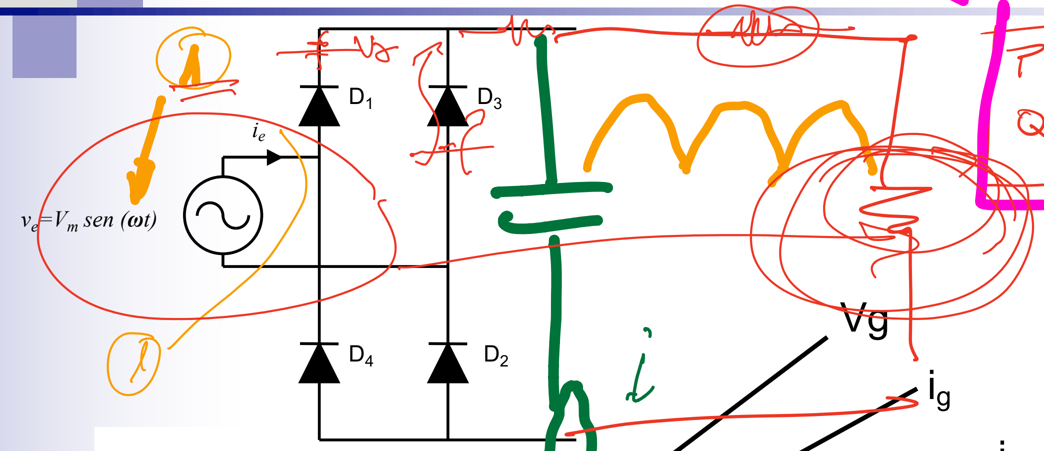
El valor eficaz al cuadrado es la suma de los cuadrados de los valores eficaces

Distorsión en la corriente de línea

50 Hz

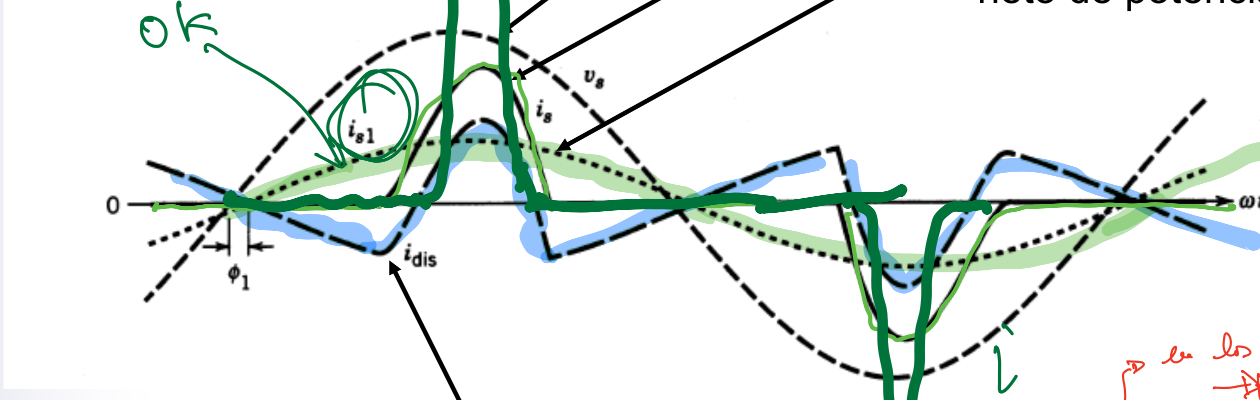
$$P = \sum V_j\, i_j \cos\varphi_j$$

$$Q = \sum V_j\, i_j \operatorname{sen}\varphi_j$$



sólo $V_1(t)$ ⇒ sólo i_{g1}

Produce intercambio neto de potencia



i_{dis}

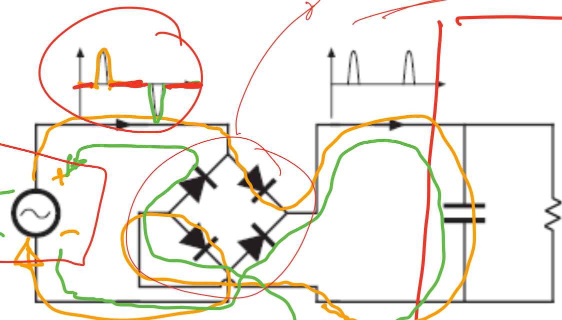
$\boxed{\text{Produce sólo pérdidas !!!}}$ → en los elementos reales ~~R~~ — cables

NO ENTREGA P a las cargas

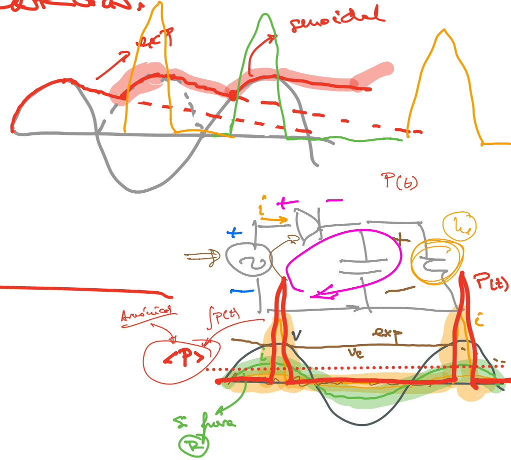
Distorsión en la corriente de línea

$\hat{V} \cdot \text{sen}\, \omega t$

No lineal → $\int p(t)\,dt$ ← visualizar
→ Armónicos



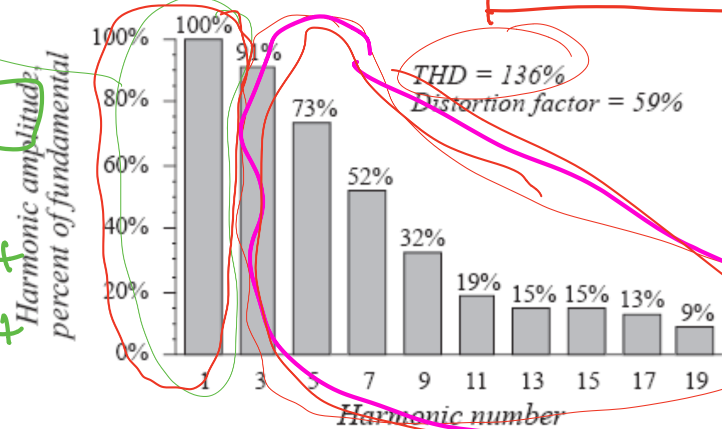
CARGA



v_1

i_1

$$P = V_{1ef} \cdot C_{1ef} \cdot \cos\varphi$$



$$P = V_{1ef} \cdot C_{1ef} \cdot \cos\varphi_1 + V_{2ef} \cdot C_{2ef} \cos\varphi_2 + \dots \infty$$

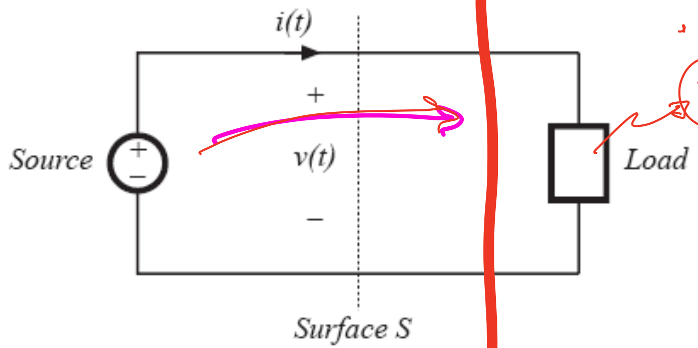
0

No entregan P a la carga.

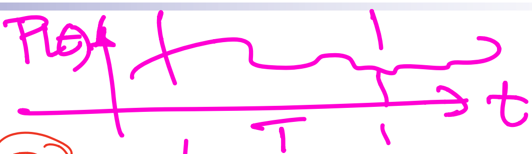
Enseguida vemos por qué es importante la THD

Potencia media

CARGA



P?



$$P = \frac{1}{T}\int_T v(t)i(t)dt$$

$P = v_1 i_1 \cdot \cos\varphi_1 + v_2 i_2 \cdot \cos\varphi_2 + \dots$

$Q = \quad \text{sen} \quad \text{sen} \quad \dots \quad \text{sen}$

$$v(t) = V_0 + \sum_{n=1}^{\infty} V_n \cos\left(n\omega t - \varphi_n\right)$$

$$i(t) = I_0 + \sum_{n=1}^{\infty} I_n \cos\left(n\omega t - \theta_n\right)$$

$$P_{av} = \frac{1}{T}\int_0^T \left(V_0 + \sum_{n=1}^{\infty} V_n \cos\left(n\omega t - \varphi_n\right)\right)\left(I_0 + \sum_{n=1}^{\infty} I_n \cos\left(n\omega t - \theta_n\right)\right)dt$$

Productos "cruzados" (diferente n)

NO PRODUCEN P.

$$\boxed{P_{av} = V_0 I_0 + \sum_{n=1}^{\infty} \frac{V_n I_n}{2} \cos\left(\varphi_n - \theta_n\right)}$$

desfase v_j e i_j

Suma de potencias de eficaces a cada frecuencia

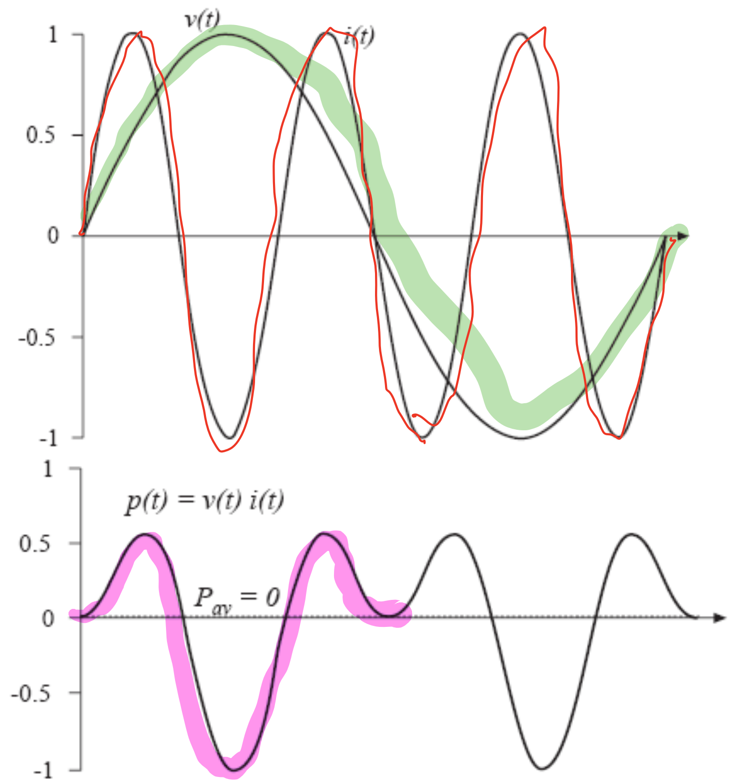
$\sqrt{\ } \quad \sqrt{\ }$

Potencia media

Ejemplo 1

Tensión fundamental

Corriente: 3er armónico



P=0

Un 3er armónico de i desde la red de 50Hz NO proporciona Pactiva !!

Potencia media

Ejemplo 2

Fourier series:

$$v(t) = 1.2\cos(\omega t) + 0.33\cos(3\omega t) + 0.2\cos(5\omega t)$$

$$i(t) = 0.6\cos(\omega t + 30°) + 0.1\cos(5\omega t + 45°) + 0.1\cos(7\omega t + 60°)$$

P_5, Q_5

Average power calculation:

$$P_{av} = \frac{(1.2)(0.6)}{2}\cos(30°) + \frac{(0.2)(0.1)}{2}\cos(45°) = 0.32$$

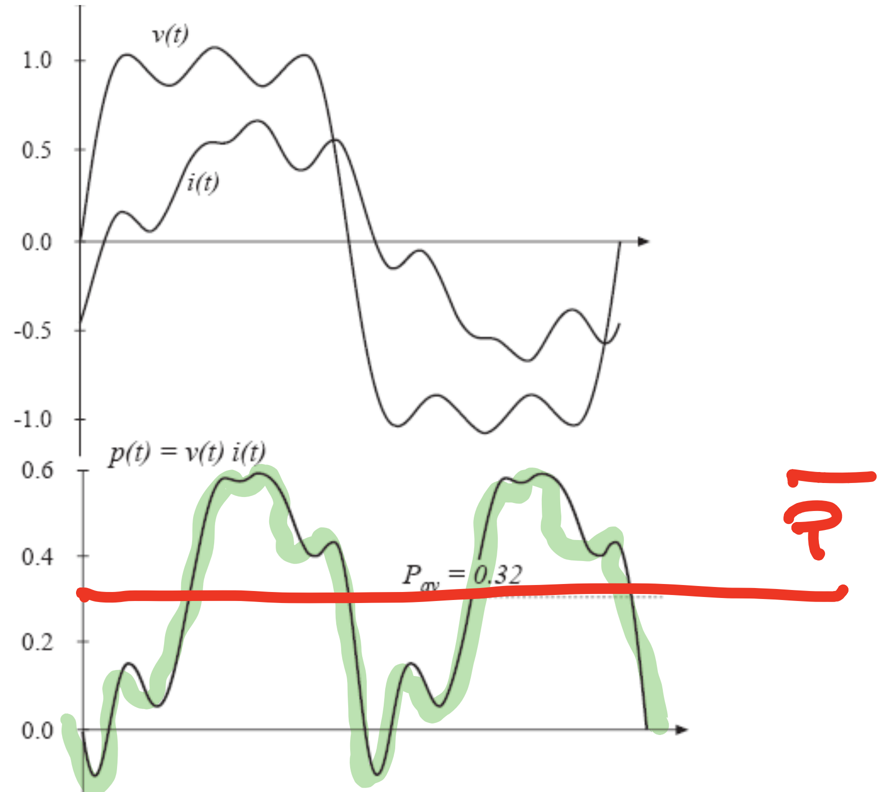
Potencia media

Ejemplo 2

Voltage: 1st, 3rd, 5th

Current: 1st, 5th, 7th

Power: net energy is transmitted at fundamental and fifth harmonic frequencies



ntals of Power Electronics   Chapter 16: Power and Harmonics in Nonsinusoidal Syst

Definiciones (I)

Factor de Potencia

$$F.P. = \frac{\frac{1}{T}\int_o^T u \cdot i \cdot dt}{\sqrt{\frac{1}{T}\int_o^T i^2 \cdot dt}\,\sqrt{\frac{1}{T}\int_o^T u^2 \cdot dt}} = \frac{\text{Potencia activa}}{\text{Potencia aparente}} = \frac{P}{S}$$

$i_{ef} = I$

$\int p(t)\,dt$ or $\sum V_{ef_j} I_{ef_j} \cos\varphi$

$V_{ef} \cdot I_{ef}$

$R \Rightarrow F.P.=1$

F.P. = cos θ sólo en régimen senoidal permanente

50Hz i 50Hz

Distorsión armónica total

$$D.A.T. = \frac{\sqrt{Ief_2^2 + Ief_3^2 + \ldots}}{Ief_1}$$

Armónicos

V_1

50Hz

$$i_{ef}^2 = i_{ef_1}^2 + \sum_2 i_{ef_j}^2$$

Definiciones (II)

Si la tensión de entrada es senoidal

Factor de Potencia

$$F.P. = \frac{Vef \cdot Ief1 \cdot \cos\theta}{Vef \cdot Ief} = \frac{Ief1}{Ief}\cos\theta = K_d \cdot K_\theta$$

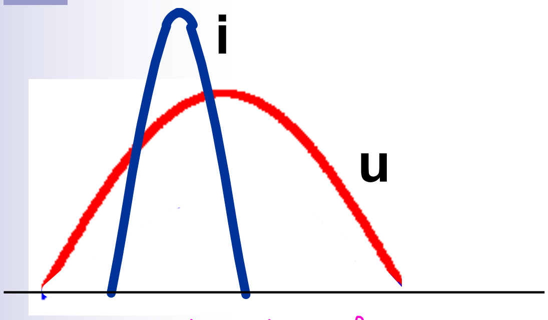
$$K_d = \frac{Ief1}{Ief} \Rightarrow factor\ de\ distorsion$$

$$K_\theta = \cos\theta \Rightarrow factor\ de\ desplazamiento$$

Relación entre FP y DAT

$$P.F. = \frac{\cos\theta}{\sqrt{1 + DAT^2}}$$

Ejemplos

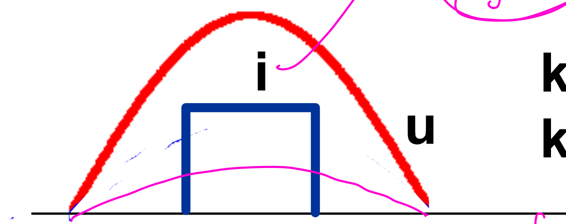


$k_d < 1$
$k_\theta < 1$

- Armónicos
- Desfase

$i_1 + \sum_j i_j$

No aportan E
Producen pérdidas en el circuito.

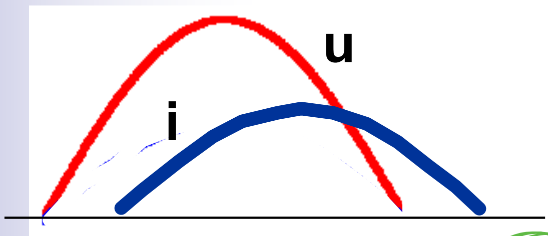


$k_d < 1$
$k_\theta = 1$

$\boxed{\varphi = 0}$

$\boxed{F.P < 1}$

$\frac{P}{S}$



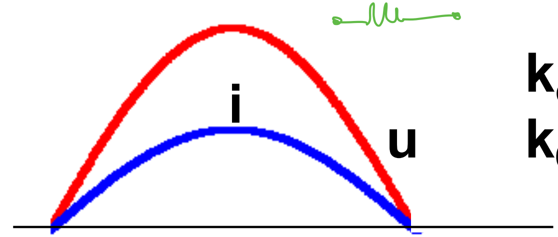
$k_d = 1$
$k_\theta < 1$

$\cos\varphi$

$P = V_{ef} \cdot I_{ef} \cdot \cos\varphi$

$F.P = \frac{\cancel{V_{ef}} \cdot \cancel{I_{ef}} \cdot \cos\varphi}{\cancel{V_{ef}} \cdot \cancel{I_{ef}}}$

R



$k_d = 1$
$k_\theta = 1$

PROBLEMA 2. (3 puntos)

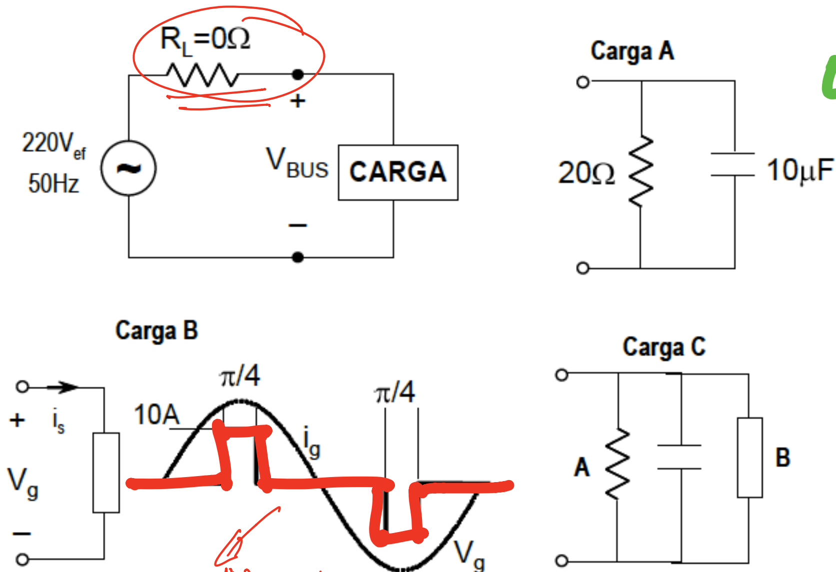
Para los siguientes tipos de carga alimentados desde un generador de tensión alterna ideal, determinar:

a) Potencia aparente manejada por el generador.

b) Potencia media consumida por la carga

c) Factor de potencia y distorsión armónica total de corriente.

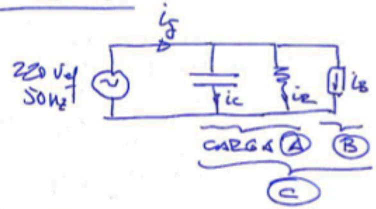
d) Suponiendo que R_L=0,1Ω, y para la carga *C*, determinar la distorsión armónica de tensión en V_{BUS} (asumir que la corriente por la carga no se ve afectada por R_L).

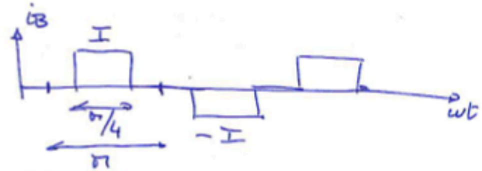


LINEAL

No Lineal.

PROBLEMAS





Fórmulas:

$$\boxed{i_{ef_B} = I\cdot\sqrt{d}} = I\cdot\sqrt{\frac{\pi/4}{\pi}} = \frac{I}{2} = 5A$$

$$\boxed{P = \frac{1}{T}\int_0^T v(t)\cdot i(t)\,dt = V_0 I_0 + V_{1ef}\, i_{1ef}\cdot\cos\varphi_1 + \dots + V_{nef}\cdot i_{nef}\cdot\cos\varphi_n}$$

$$\boxed{V_{ef}^2 = V_{1ef}^2 + V_{2ef}^2 + \dots} \Rightarrow \boxed{\sum_2^\infty V_{ef_n}^2 = V_{ef}^2 - V_{1ef}^2}$$

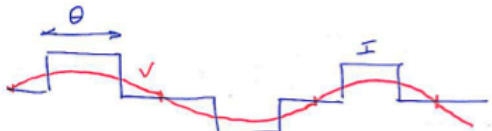
$$\boxed{F.P = \frac{P}{S}}$$

$$\boxed{S = P + jQ = V_{ef}\cdot I_{ef}^*}$$

$$\boxed{|S| = \sqrt{P^2 + Q^2} = V_{ef}\cdot I_{ef}}$$

$$\boxed{THD = \frac{\sqrt{i_{ef_2}^2 + i_{ef_3}^2 + \dots}}{i_{ef_1}} = \sqrt{\frac{i_{ef}^2}{i_{ef_1}^2} - 1}}$$

Cálculo del armónico n:



$$P = \frac{1}{\pi}\int_{-\theta/2}^{\theta/2} I\cdot V_p\cdot\cos n\omega t\, d\omega t = V_0 I_0 + V_{1ef}\cdot i_{1ef}\cdot\cos\varphi_1 + \dots + V_{nef}\cdot i_{nef}\cdot\cos\varphi_n$$

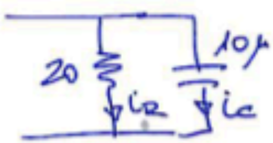
$$\frac{1}{\pi\cdot n}\cdot I\cdot V_p\cdot\left[\operatorname{sen} n\omega t\right]_{-\theta/2}^{\theta/2} = V_{ef_n}\cdot i_{ef_n}\cdot\cos\varphi_n = \frac{V_p}{\sqrt{2}}\cdot i_{ef_n}$$

$$\boxed{i_{ef_n} = I\cdot\frac{1}{\pi\cdot n}\cdot 2\cdot\sqrt{2}\cdot\operatorname{sen} n\frac{\theta}{2}}$$

$$\boxed{i_n(t) = I\cdot\frac{4}{\pi\cdot n}\cdot\operatorname{sen} n\frac{\theta}{2}\cdot\operatorname{sen} n\omega t}$$

	i_{ef_g}	$i_{g_{ef_1}}$	$\sqrt{\sum_2 i_{g_{ef_j}}^2}$	P(W)	S(VA)	F.P	THD
Carga Ⓐ	$11+j0'69 = 11'02 \angle 3'58^\circ$	$i_{g_{ef}} \equiv i_{g_{1ef}}$	0	$\frac{220^2}{R} = 2420$	$220 \cdot 11'02 = 2424$	$\frac{P}{S} = \frac{2420}{2424} = 0'998$	0
" Ⓑ	5A	3'445	13'129	758	$220 \cdot 5 = 1100$	$\frac{758}{1100} = 0'69$	105 %
" Ⓒ	14'90	14'46	13'129	3178	$220 \cdot 14'9 = 3280$	$\frac{3178}{3280} = 0'97$	25 %

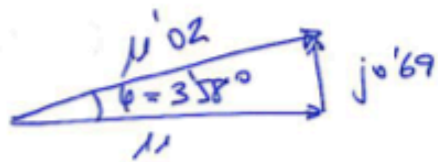
Carga Ⓐ :



$$i_{R_{ef_1}} = \frac{220}{\sqrt{2}} = 11$$

$$i_{C_{ef_1}} = \frac{220}{1/j\omega L} = 220 \cdot 2\pi \cdot 50 \cdot 10 \cdot 10^{-6} = j\,0'69$$

50 Hz



Carga (B):

$$\begin{cases} I_{ef_0} = 10 \cdot \sqrt{\dfrac{\pi/4}{\pi}} = 5\,A \\ I_{ef_{B_1}} = \dfrac{I}{\pi} \cdot 2 \cdot \sqrt{2} \cdot \operatorname{sen} \dfrac{\pi}{8} = 3'445\,A \end{cases}$$

$$\boxed{\sum_{n=2}^{\infty} I^2_{ef_n} = 5^2 - 3'445^2 = 13'129}$$

$$P = \frac{1}{\pi} \int_{-\pi/8}^{\pi/8} I \cdot V_p \cdot \cos\omega t \, d\omega t = \frac{I \cdot V_p}{\pi} \cdot 2 \cdot \operatorname{sen} \frac{\pi}{8} = \frac{10 \cdot 220 \cdot \sqrt{2} \cdot 2}{\pi} \cdot \operatorname{sen} \frac{\pi}{8} = \boxed{758\,W}$$

$$F.P = \frac{758}{220 \cdot 5} = \boxed{0'69 = 69\%}$$

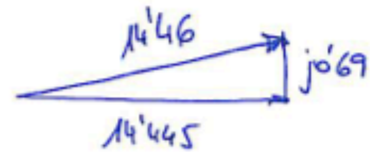
$$THD = \frac{\sqrt{13'129}}{3'445} = 1'05$$

Carga (C).

$$P_C = P_A + P_B = 758 + 2420 = \boxed{3178\,W}$$

$$\sum_{n=2}^{\infty} I^2_{ef_n} = 13'129, \text{ igual que en B}$$

Primer armónico: $11 + 3'445 + j0'69 = 14'445 + j0'69$

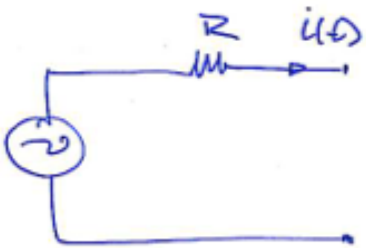


$$I^2_{ef_C} = I^2_{ef_{C_1}} + \sum_{n=2}^{\infty} I^2_{ef_n} = 14'46^2 + 13'129 = 222 \Rightarrow \boxed{I_{ef_C} = 14'9}$$

$$F.P = \frac{P}{S} = \frac{3178}{220 \cdot 14'9} = \boxed{0'97}$$

$$\boxed{THD = \frac{\sqrt{13'129}}{14'46} = 0'25}$$

THD de v, conocida $\sum_{n=2}^{\infty} i_{ef_n}^2$:

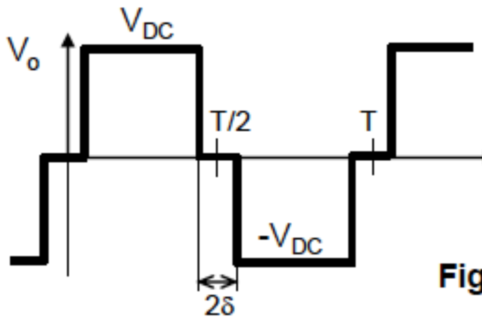


$$\boxed{THD = \frac{\sqrt{\sum i_{ef_n}^2 \cdot R}}{V_{ef_1}} = \frac{R}{V_{ef_1}} \cdot \sqrt{\sum_{n=2}^{\infty} i_{ef_n}^2}}$$

$$\boxed{THD} = \frac{0'1}{220} \cdot \sqrt{13'129} = \boxed{0'16\,\%}$$

PROBLEMA 3. (2,5 ptos)

La descomposición en serie de Fourier de la forma de onda de la Figura 1 es la que se muestra a su derecha.



$$v_o(t) = V_{DC} \sum_{n=1,3,5} \frac{4}{n\pi} \cos(n\delta)\sin(n\omega t)$$

Figura 1

El circuito de la figura 2 representa un inversor no modulado que puede inyectar y absorber potencia de la red eléctrica. El inversor genera una tensión desfasada de un ángulo Φ respecto a la tensión de red, tal y como se muestra en la figura 3.

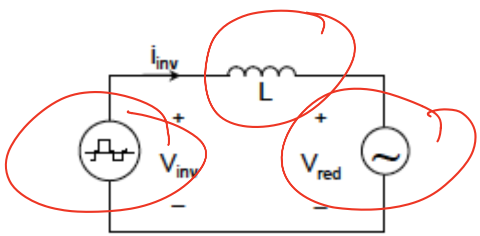


Figura 2

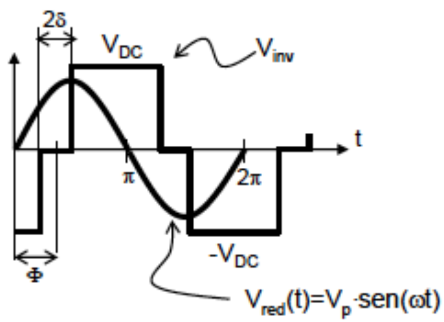


Figura 3

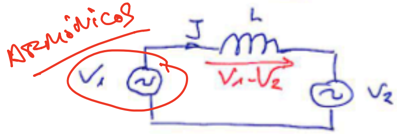
Datos:

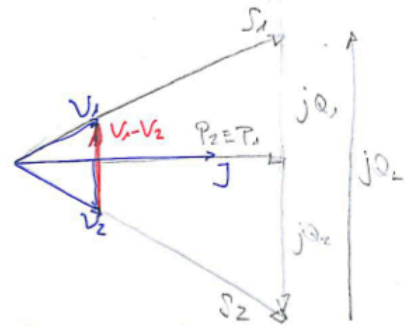
L=2mH
$\delta=37^o$
$\Phi=10^o$
V_p=300V
V_{DC}=300V
f=50Hz

Calcular:

a) Amplitud de los armónicos 1, 3 y 5 de corriente (valor de pico).
b) Potencia inyectada a la red por los armónicos 1, 3 y 5 de corriente (signo positivo absorbida por la red).
c) Potencia que el inversor inyecta debida a los armónicos 1, 3 y 5.
d) Factor de potencia en el lado de la red y factor de potencia en el lado del inversor (hasta 5º armónico).
e) Distorsión armónica total de la corriente (hasta 5º armónico).

FLUJO DE POTENCIA





$$\boxed{J = \frac{V_1 - V_2}{j\omega L}}$$

$$\boxed{S_1 = V_1 \cdot J_1^*} = V_1 \cdot \frac{V_1^* - V_2^*}{-j\omega L} = -\frac{V_1^2}{j\omega L} + \frac{V_1 \cdot V_2^*}{j\omega L}$$

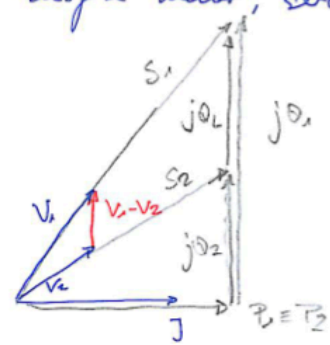
$$P_1 = P_2 = Re\left\{\frac{V_1 \cdot V_2^*}{j\omega L}\right\} = \frac{V_1 \cdot V_2}{\omega L} \cdot \cos(\varphi_1 - \varphi_2 - 90^\circ)$$

$$\boxed{P_1 = \frac{V_1 \cdot V_2}{\omega L} \cdot \text{sen}(\varphi_1 - \varphi_2)} \equiv P_2$$

$$Q_1 = Im\left\{j\frac{V_1^2}{\omega L} + \frac{V_1 \cdot V_2^*}{j\omega L}\right\}$$

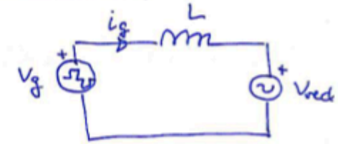
$$Q_1 = \frac{V_1^2}{\omega L} + \frac{V_1 V_2}{\omega L} \cdot \text{sen}(\varphi_1 - \varphi_2 - 90^\circ) = \boxed{\frac{V_1^2}{\omega L} + \frac{V_1 V_2}{\omega L} \cdot \cos(\varphi_1 - \varphi_2)}$$

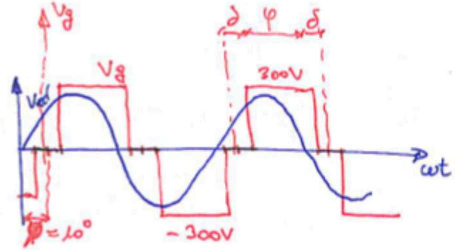
Con un desfase tan grande las dos fuentes aportan reactiva a la L. Con un desfase menor, sería:



La P va de la V más adelantada hacia la retrasada,
por lo que sería mejor resolverlo con el desfase al revés ($v_{\_inversor}$ adelantada respecto a $v_{\_red}$)

PROBLEMAS





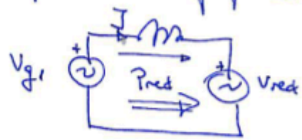
origen de tiempos en ωt = 10°

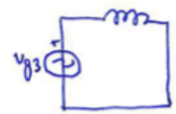
$$v_g = \left[\frac{4}{\pi}\cdot\cos\delta\cdot\sin\omega t + \frac{4}{3\pi}\cdot\cos 3\delta\cdot\sin 3\omega t + \frac{4}{5\pi}\cdot\cos 5\delta\cdot\sin 5\omega t + \dots\right]\cdot 300$$

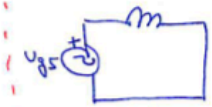
$$= \frac{4}{\pi}\sin\frac{\varphi}{2}\cdot\sin\omega t + \frac{4}{3\pi}\cdot\sin\frac{3\varphi}{2}\cdot\sin 3\omega t + \frac{4}{5\pi}\cdot\sin\frac{5}{2}\varphi\cdot\sin 5\omega t + \dots\Big]\cdot 300$$

Siendo $\varphi = \pi - 2\delta \Leftrightarrow \delta = \frac{\pi-\varphi}{2} \Rightarrow \cos\delta = \sin\frac{\varphi}{2}$

Aplicamos superposición para cada armónico:







$$V_{g1,ef} = \frac{4}{\pi}\cos\delta\cdot 300\cdot\frac{1}{\sqrt{2}} = 215'7\text{ V}$$

$$V_{g1} = 215'7\cdot\sqrt{2} = 305\text{ V}$$

$$I_{ef3} = \frac{V_{g3ef}}{3\omega L} = \frac{\frac{4}{3\pi}\cos 3\delta\cdot 300}{\sqrt{2}\cdot 3\cdot 100\pi\cdot 2\cdot 10^{-3}} = \frac{\cancel{4}\sqrt{2}\cos 3\delta}{3\pi^2\cdot\cancel{2}}\cdot 10^3 = \boxed{17'1}$$

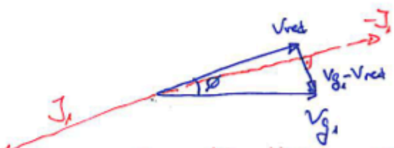
$$\boxed{P_3 = 0}$$

$$I_{p3} = \sqrt{2}\, I_{ef3} = \boxed{24'2}$$

$$I_{ef5} = \frac{V_{g5ef}}{5\omega L} = \frac{\frac{4}{5\pi}\cdot\cos 5\delta\cdot 300}{\sqrt{2}\cdot 5\cdot 100\pi\cdot 2\cdot 10^{-3}} = \frac{2\sqrt{2}\cdot\cos 5\delta\cdot 300}{5\cdot\pi^2\cdot 100\cdot 2\cdot 10^{-3}} = \boxed{17'1}$$

$$\boxed{P_5 = 0}$$

$$I_{p5} = \sqrt{2}\, I_{ef5} = \boxed{24'2}$$



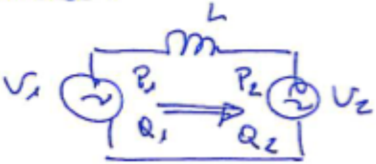
$$I_1 = \frac{V_{g1} - V_{red}}{j\omega L} = \frac{215'7 - \frac{300}{\sqrt{2}}\cdot e^{j10}}{j\, 2\pi\cdot 50\cdot 2\cdot 10^{-3}} = -58'6 - j\,10'8 \Rightarrow I_{1ef} = 59'6$$

$$S_{red} = V_{red}\cdot I^* = V_{red}\cdot\left(\frac{V_g - V_{red}}{j\omega L}\right)^* = V_{red}\cdot\frac{V_{g1}^* - V_{red}^*}{-j\omega L}$$

$$S_{red} = \frac{V_{red}\cdot V_{g1}^*}{-j\omega L} + \frac{V_{red}^2}{j\omega L}$$

$$\boxed{P_{red_1} = \frac{V_{red}\cdot V_{g1}}{\omega L}\cdot\cos(\phi + 90^\circ)} = -\frac{\frac{300}{\sqrt{2}}\cdot 215'7}{100\pi\cdot 2\cdot 10^{-3}}\cdot\sin 10^\circ = \boxed{-12\,645\text{ W}}$$

En general:



$$\boxed{\begin{aligned} P_2 &= \frac{V_1 \cdot V_2}{\omega L} \cdot \operatorname{sen}(\varphi_1 - \varphi_2) = P_1 \\ Q_2 &= \frac{V_1 \cdot V_2}{\omega L} \cdot \cos(\varphi_2 - \varphi_1) + \frac{V_2^2}{\omega L} \neq Q_1 \end{aligned}}$$

d) Factor de Potencia

$$I_{ef}^2 = I_{ef_1}^2 + I_{ef_3}^2 + I_{ef_5}^2 \Rightarrow I_{ef} = \sqrt{59'6^2 + 17'1^2 + 17'1^2} = 64'3$$

$$F.P_{red} = \frac{P}{V_{ef_{red}} \cdot I_{ef}} = \frac{12\,645}{\frac{300}{\sqrt{2}} \cdot 64'3} = \boxed{0'927}$$

$$F.P_g = \frac{P}{V_{ef_g} \cdot I_{ef}} = \frac{12645}{300 \cdot \sqrt{1 - \frac{2\delta}{\pi}} \cdot 64'3} = \frac{12645}{300 \cdot 0'767 \cdot 64'3} = \boxed{0'85}$$

e) $$THD = \frac{\sqrt{I_{ef_3}^2 + I_{ef_5}^2}}{I_{ef_1}} = \frac{\sqrt{17'1^2 + 17'1^2}}{59'6} = \boxed{0'4 = 40\%}$$