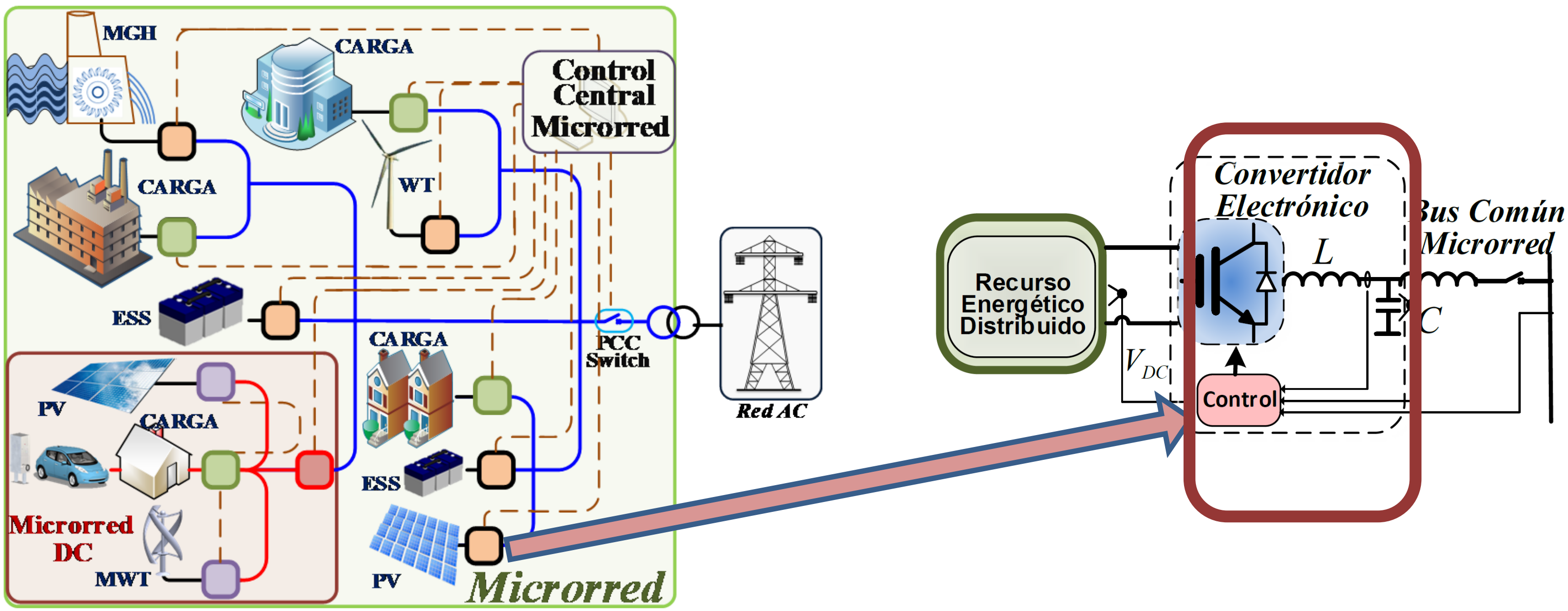
# Microrredes Eléctricas

# 2
# AC Microgrids

1. Introduction.
2. Topological operation of Power Electronics Converters.
    1. Power Inverter.
    2. Syncronization.
    3. Control and operation Topologies.
    4. Interaction of Power Converters

# Microgrid


MGH
CARGA
Control Central Microrred
CARGA
WT
ESS
PCC Switch
Red AC
CARGA
PV
CARGA
ESS
Microrred DC
MWT
PV
Microrred
Recurso Energético Distribuido
Convertidor Electrónico
Bus Común Microrred
L
C
$V_{DC}$
Control

## Control Structure for a Microgrid

A control system in a microgrid includes the control functions that define the microgrid as a self-manageable system, capable of operating autonomously or while connected to the grid, as well as the ability to connect and disconnect from the main grid for energy exchange or provision of auxiliary services. It is the sole point of interface with any device within the distributed energy resources (DER) or their management system (DERMS), or the energy management system (EMS). It must have real-time control and energy management functions that operate in the following situations:

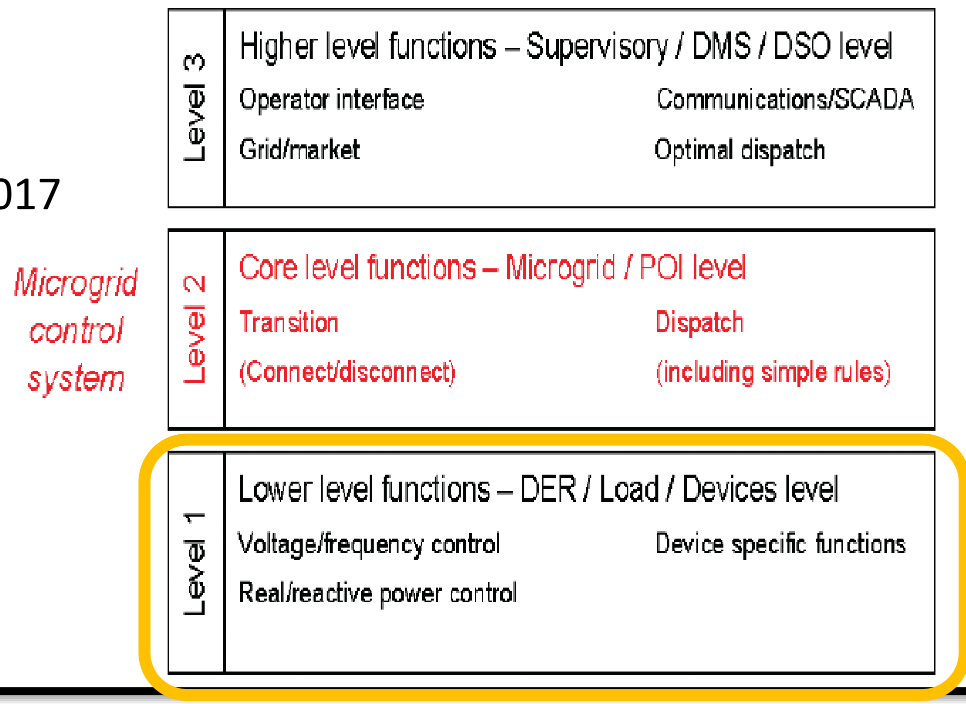
- Operate in island mode or connected to the grid.
- Automatic transition from isolated mode to grid-connected mode.
- Resynchronization and reconnection from island mode to grid-connected mode.
- Energy Management System (EMS) for the optimization of active and reactive energy consumption.
- Provide auxiliary functions, grid support, participation in the energy market, and operation of the electrical system.

IEEE Standard 20307_2017

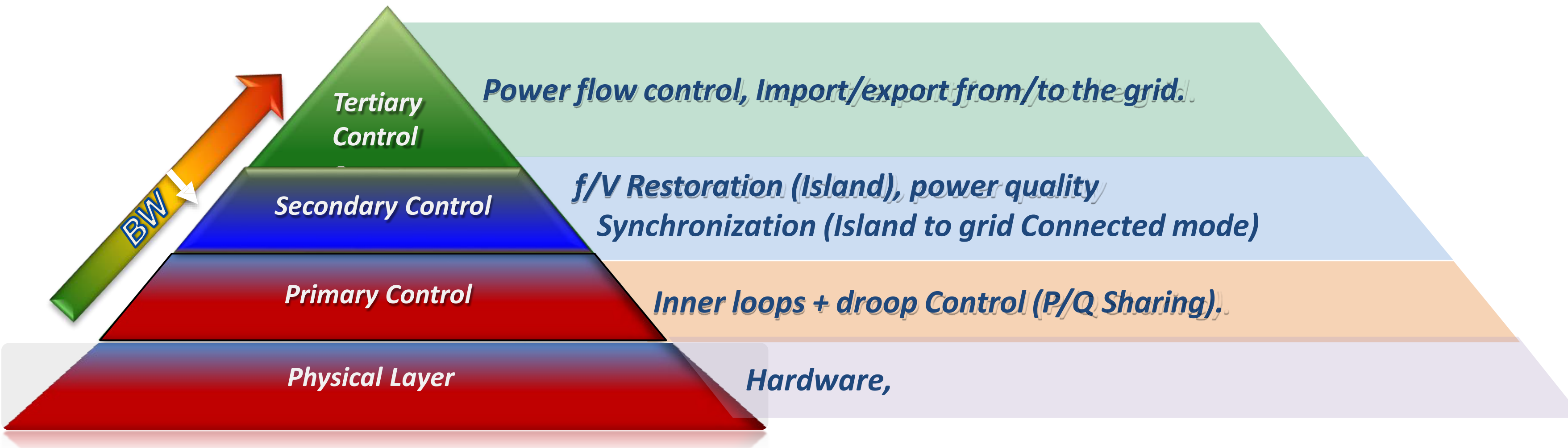
# Hierarchical Control Structure in a Microgrid

For the purposes of interconnection, a microgrid will appear to the connected grid as a single controllable entity. The control system is the system that achieves this objective. It meets the interconnection requirements using high-level, central-level, or low-level functions within its operations.

IEEE Standard 20307_2017



# Hierarchical Control Structure in a Microgrid



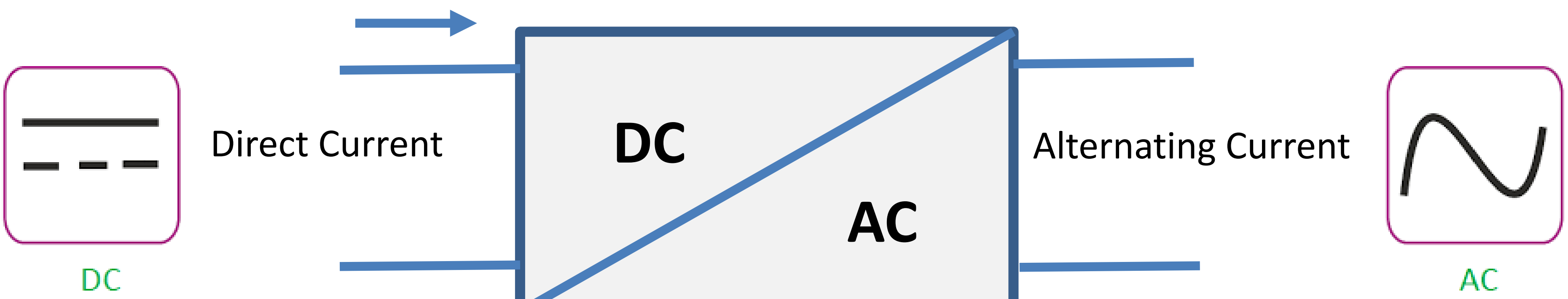

J. C. Vasquez, J. M. Guerrero, J. Miret, M. Castilla and L. Garcia de Vicuna, "Hierarchical Control of Intelligent Microgrids," in *IEEE Industrial Electronics Magazine*, vol. 4, no. 4, pp. 23-29, Dec. 2010.

# Physical Layer

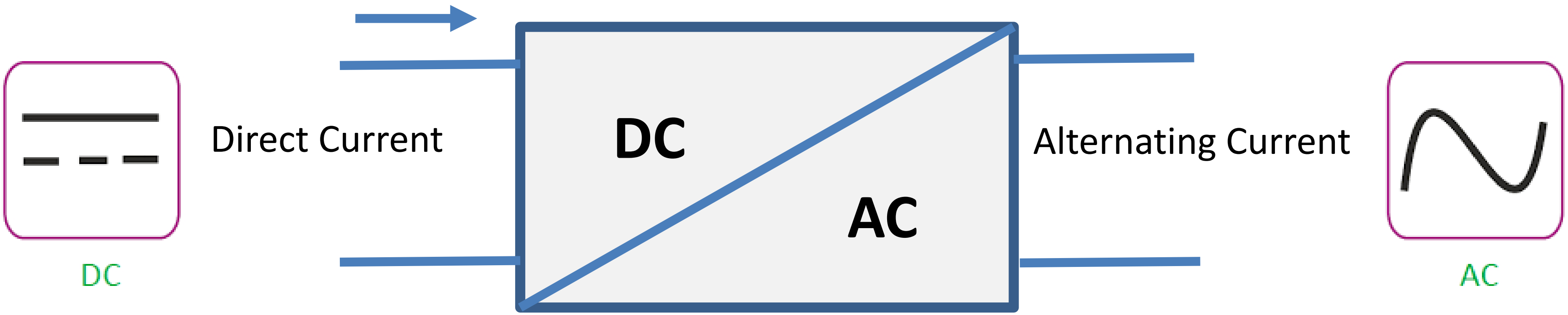
# Three phase line.

# Inverter.

An inverter is considered any circuit able to transform direct current (DC) into Alternating current (AC).



# Inverter.

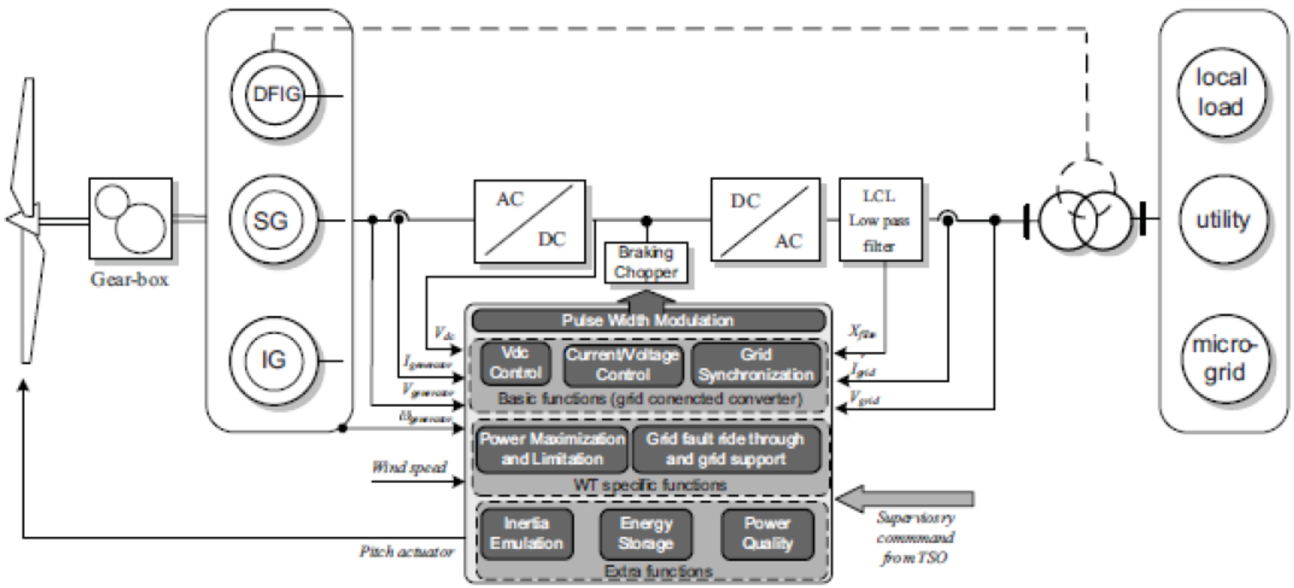



- *IEEE 1547 Interconnection of Distributed Generation*.

- DC/AC Conversion.
- Grid Current Control.
- Grid Synchronization.
- DC Voltage Control.
- Maximum Power Point Tracking (MPPT).
- Islanding Detection.
- Ancillary Support.

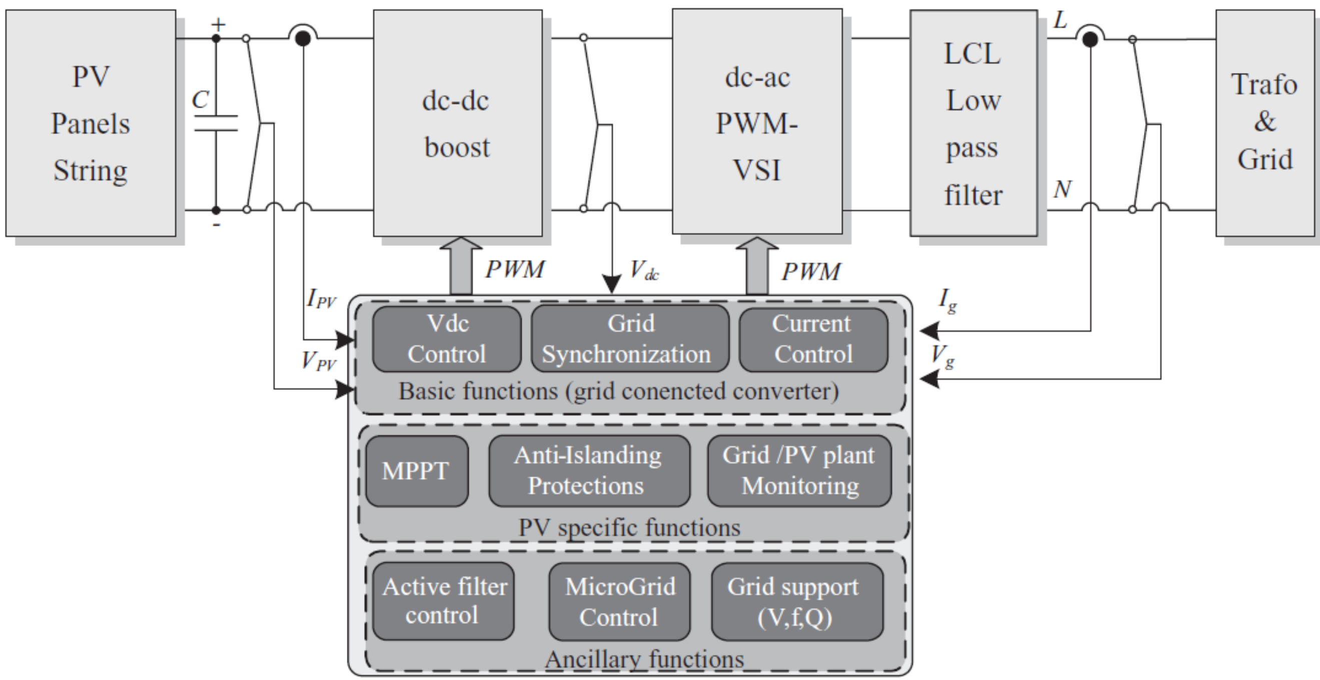
# Examples.

## Wind turbine control structure:



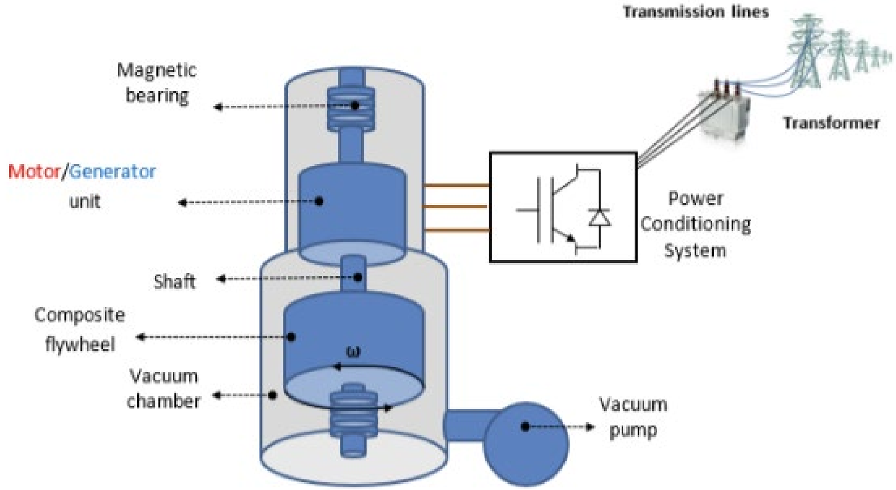

Teodorescu, R., Liserre, M., & Rodriguez, P. (2011). *Grid converters for photovoltaic and wind power systems*. John Wiley & Sons.

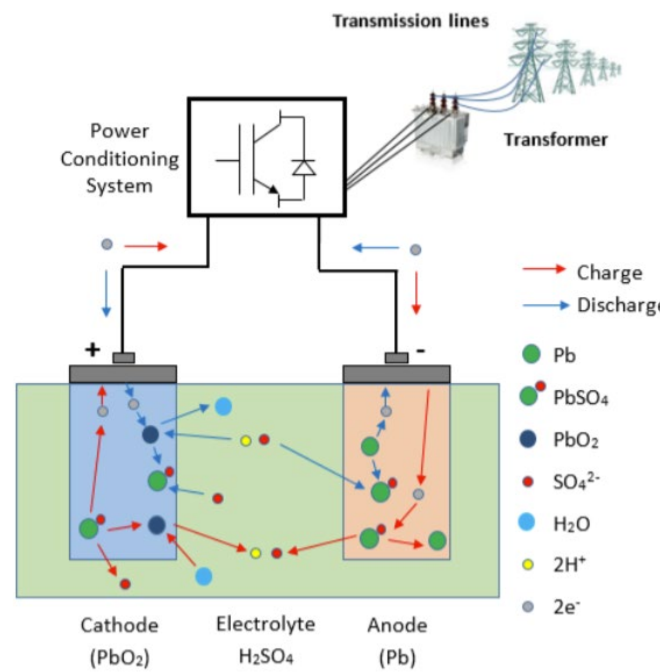
# Examples.




Teodorescu, R., Liserre, M., & Rodriguez, P. (2011). *Grid converters for photovoltaic and wind power systems*. John Wiley & Sons.

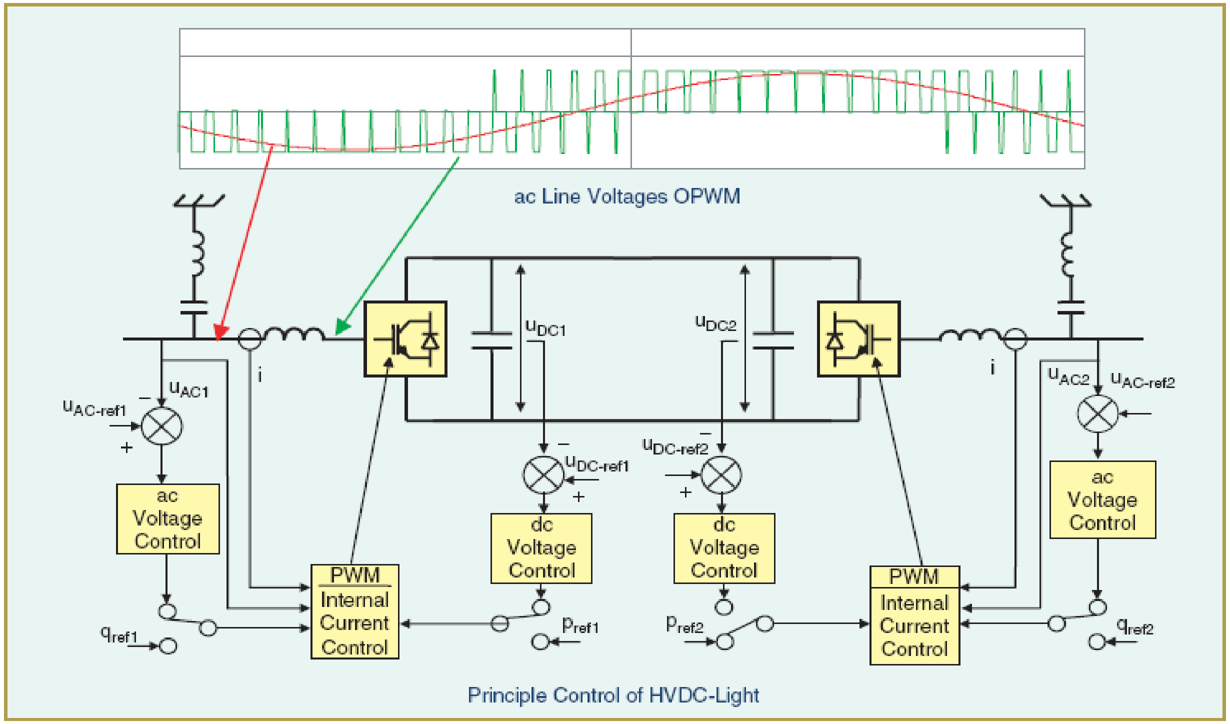
# Examples.




Nikolaidis, Pavlos & Poullikkas, Andreas. (2017). Journal of Power Technologies 97 (3) (2017) 220-245 A comparative review of electrical energy storage systems for better sustainability.

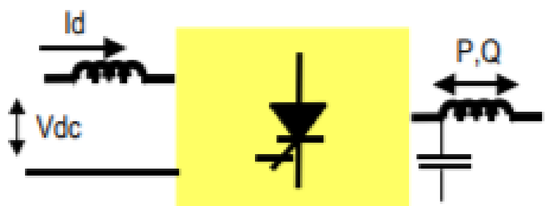
# Examples.

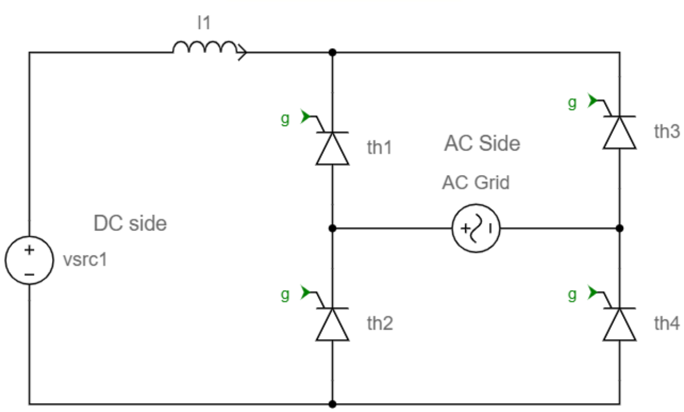



"*The ABC of the HVDC technology*" IEEE Power & Energy Magazine March/April 2007 Vol. 5 No. 2

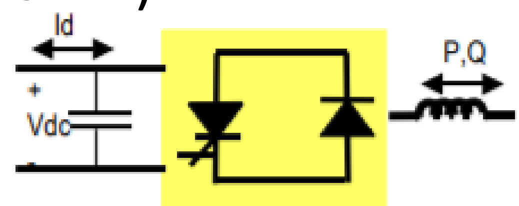
# Power Inverter.

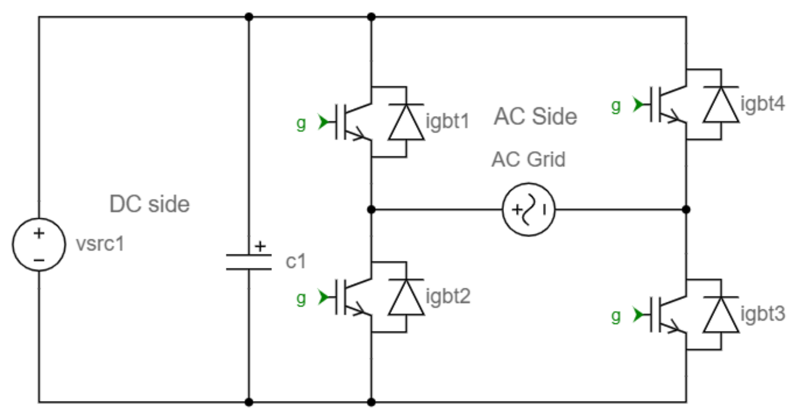
- Current Source Inverter (CSI).
  - Supplied by a constant current.
  - Line commutated switches (Thyristors).



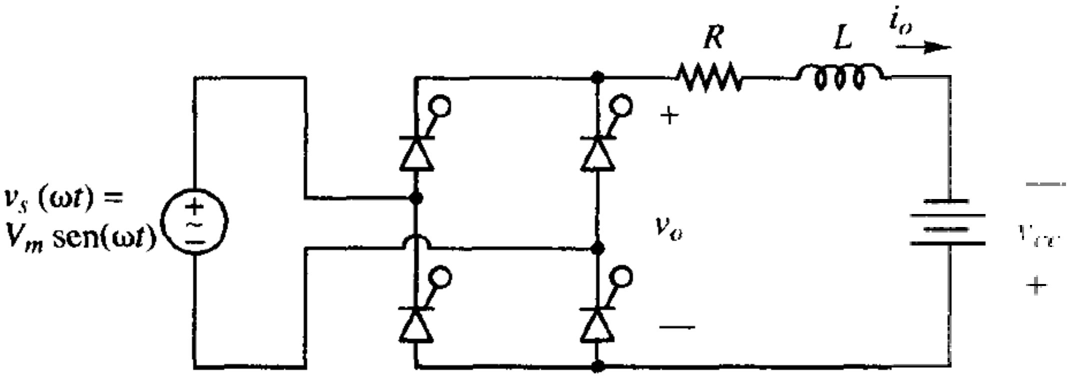

- Voltage Source Inverter (VSI).
  Supplied by a constant voltaje source.
  Self-commutated switches (IGBT, MOSFET).

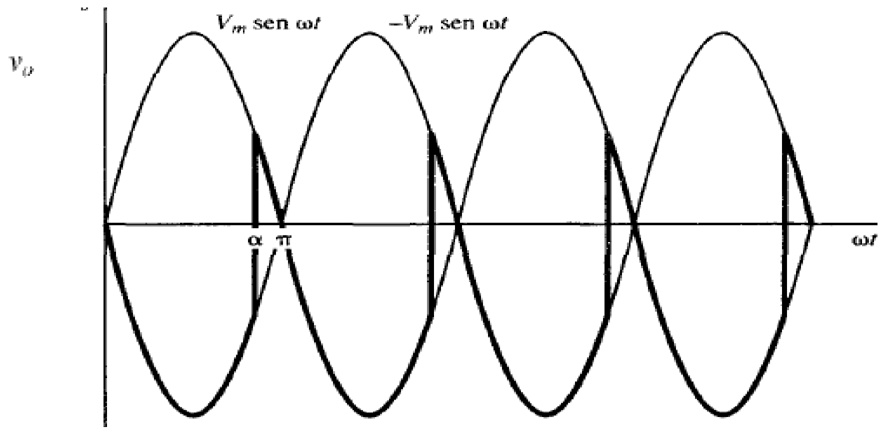


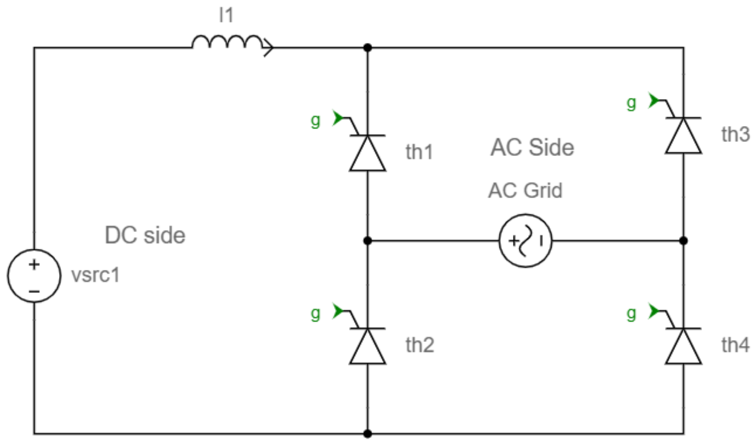
# Thyristor Based Inverter

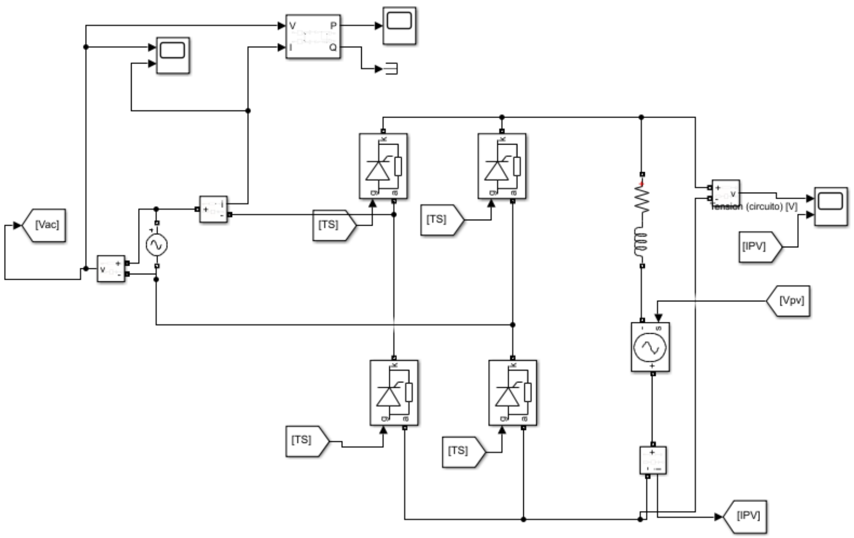
- SCR.



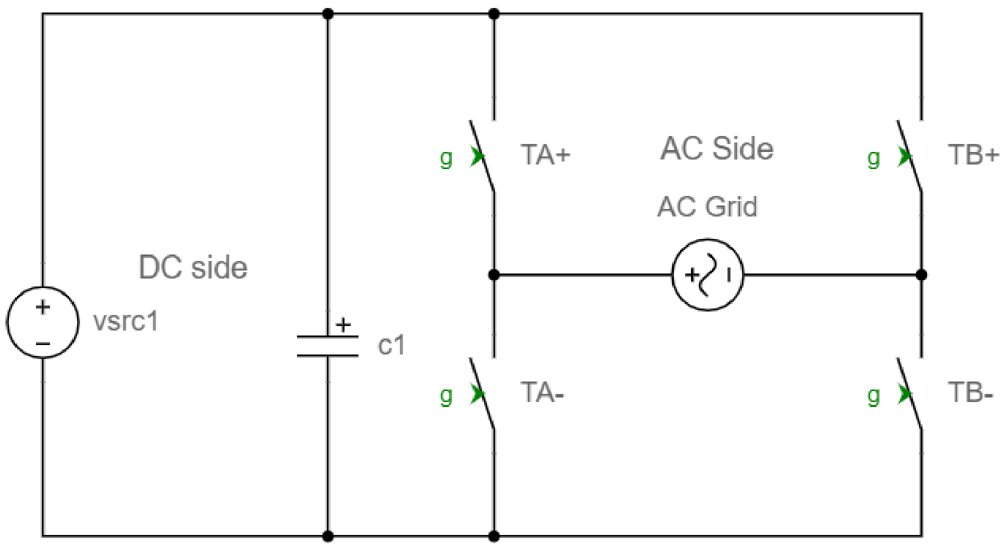
# Thyristor Based Inverter

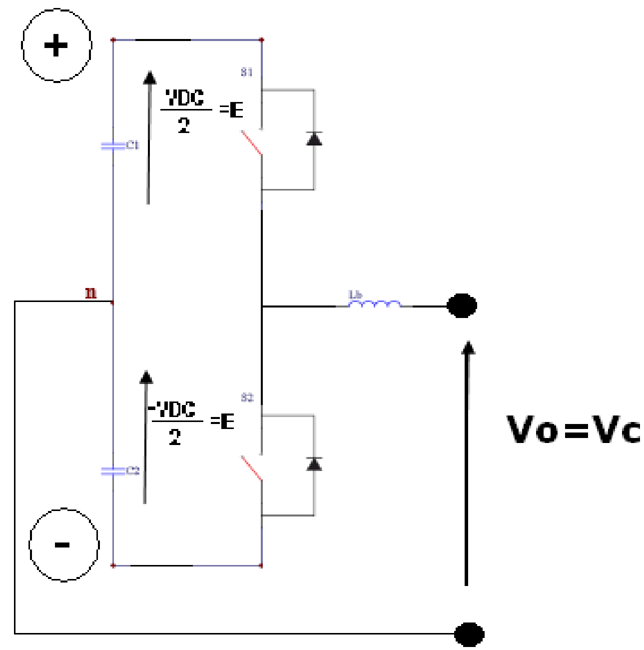


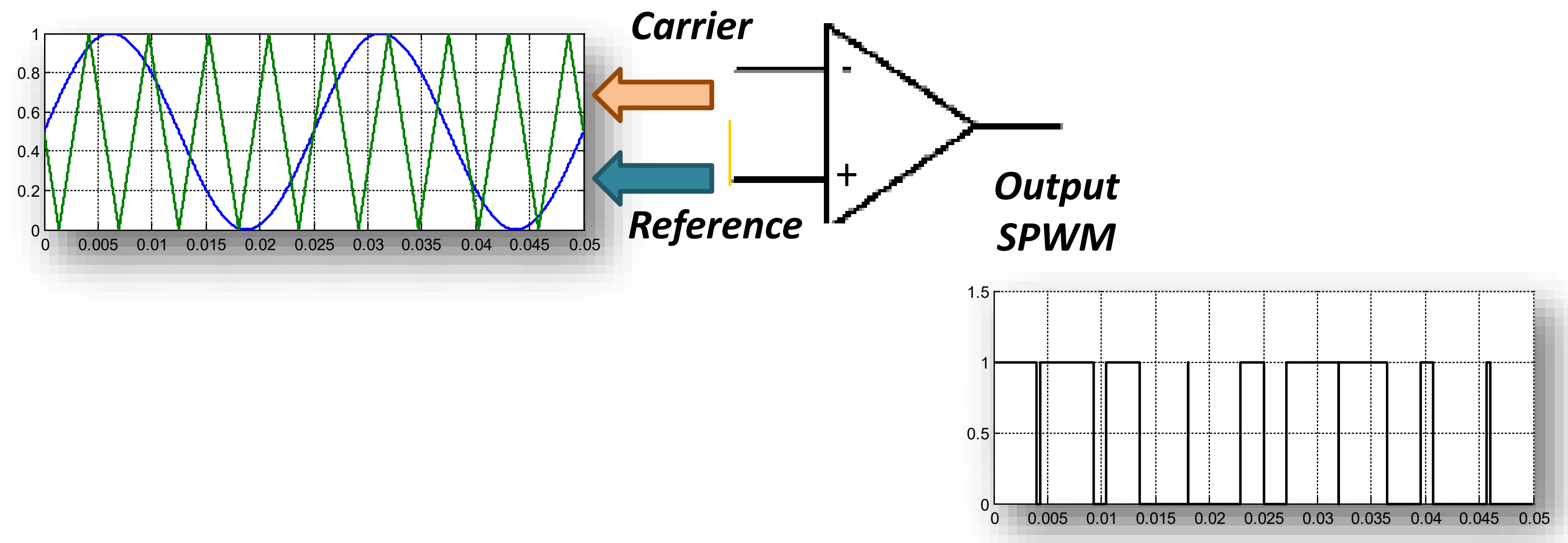

Simulation1 File.

# Self-Commutated Switches

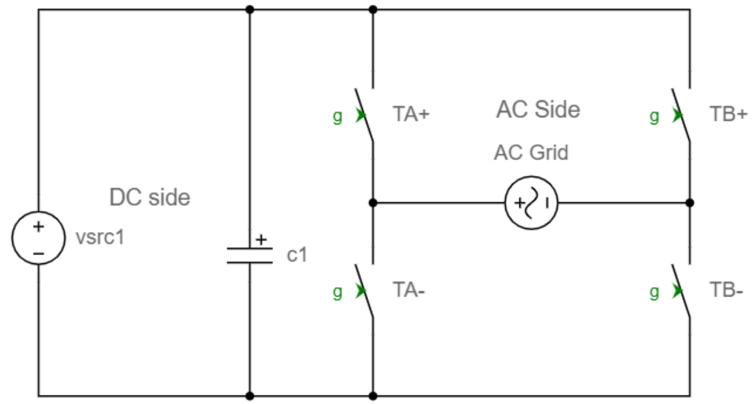


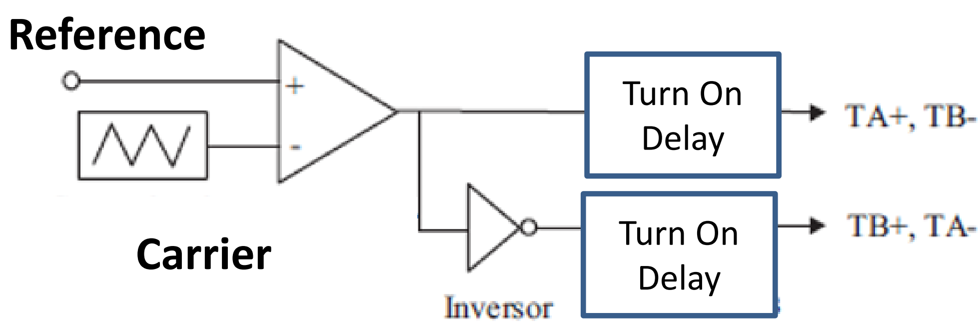
# PWM


Carrier
Reference
-
+
Output
SPWM
1
0.8
0.6
0.4
0.2
0
0 0.005 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045 0.05
1.5
1
0.5
0
0 0.005 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045 0.05

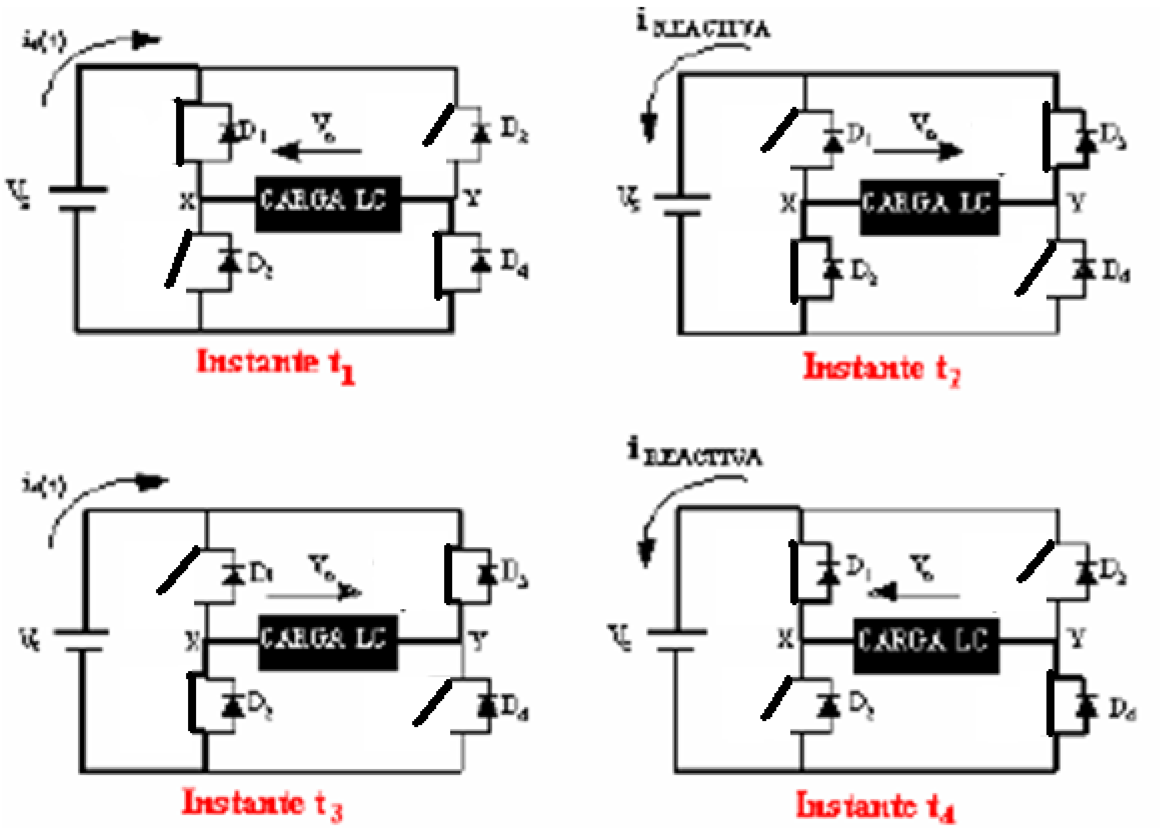
# PWM Modulation

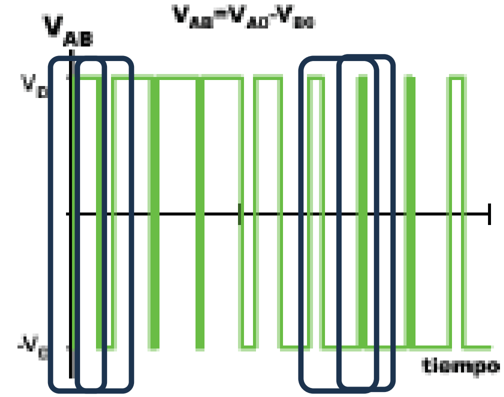



Bipolar

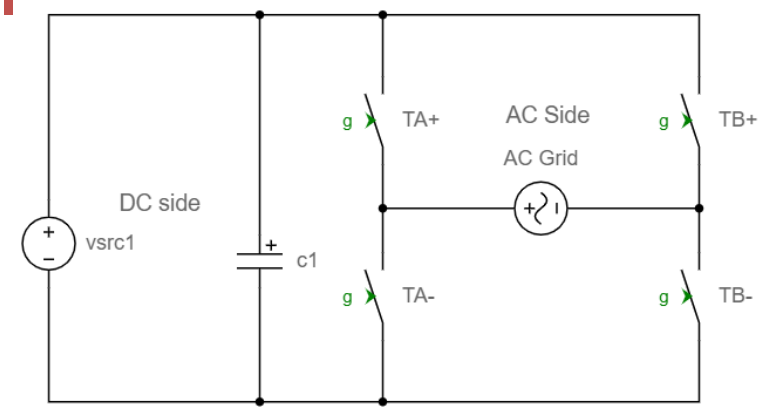


# PWM Modulation

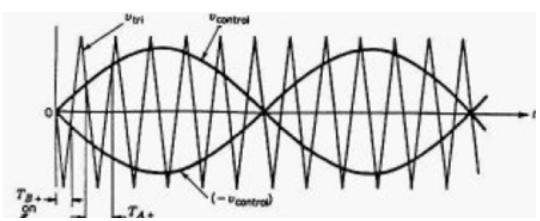


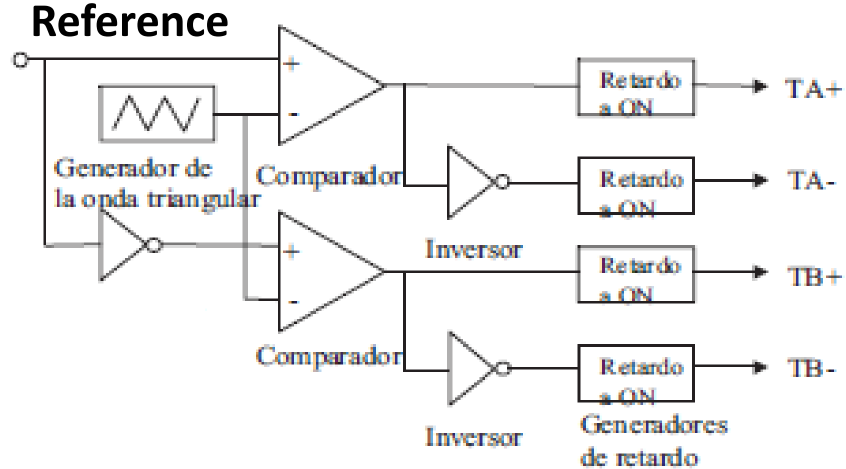
# PWM Modulation



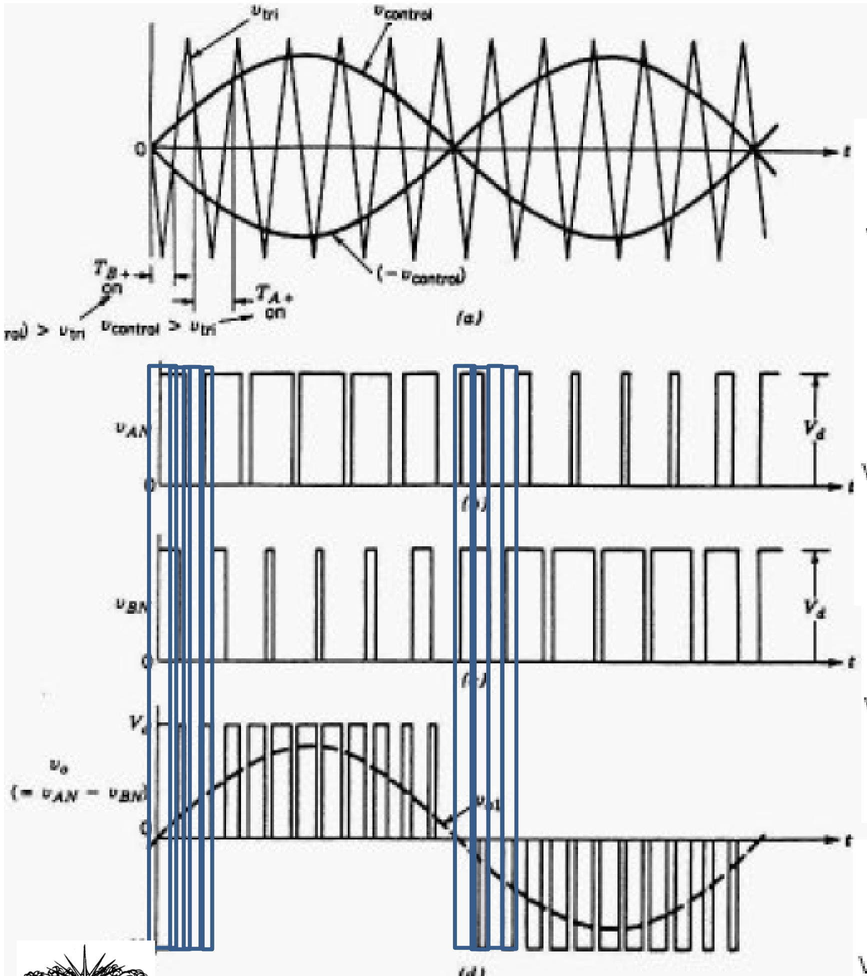

Unipolar



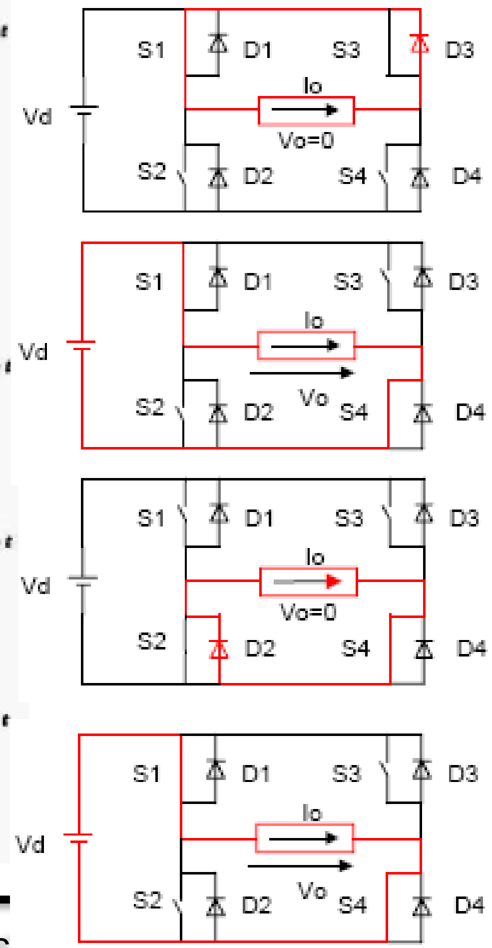
**Reference**



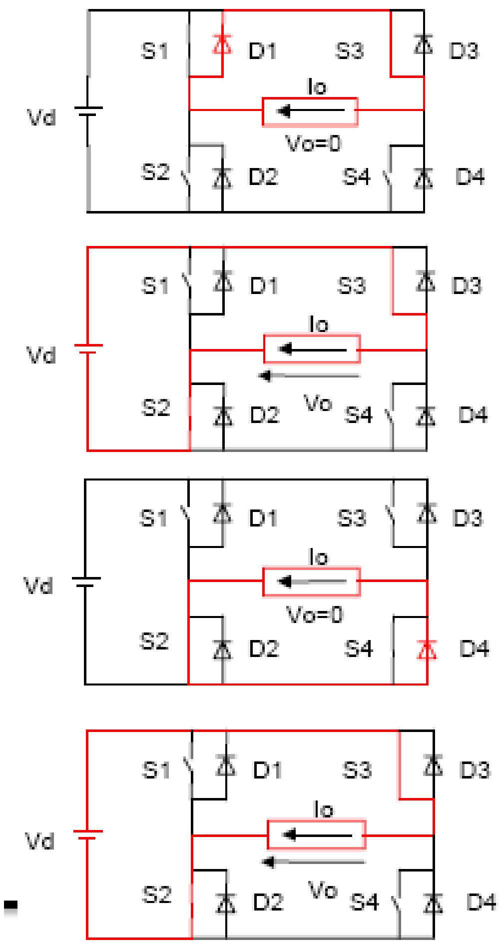
# PWM Modulation



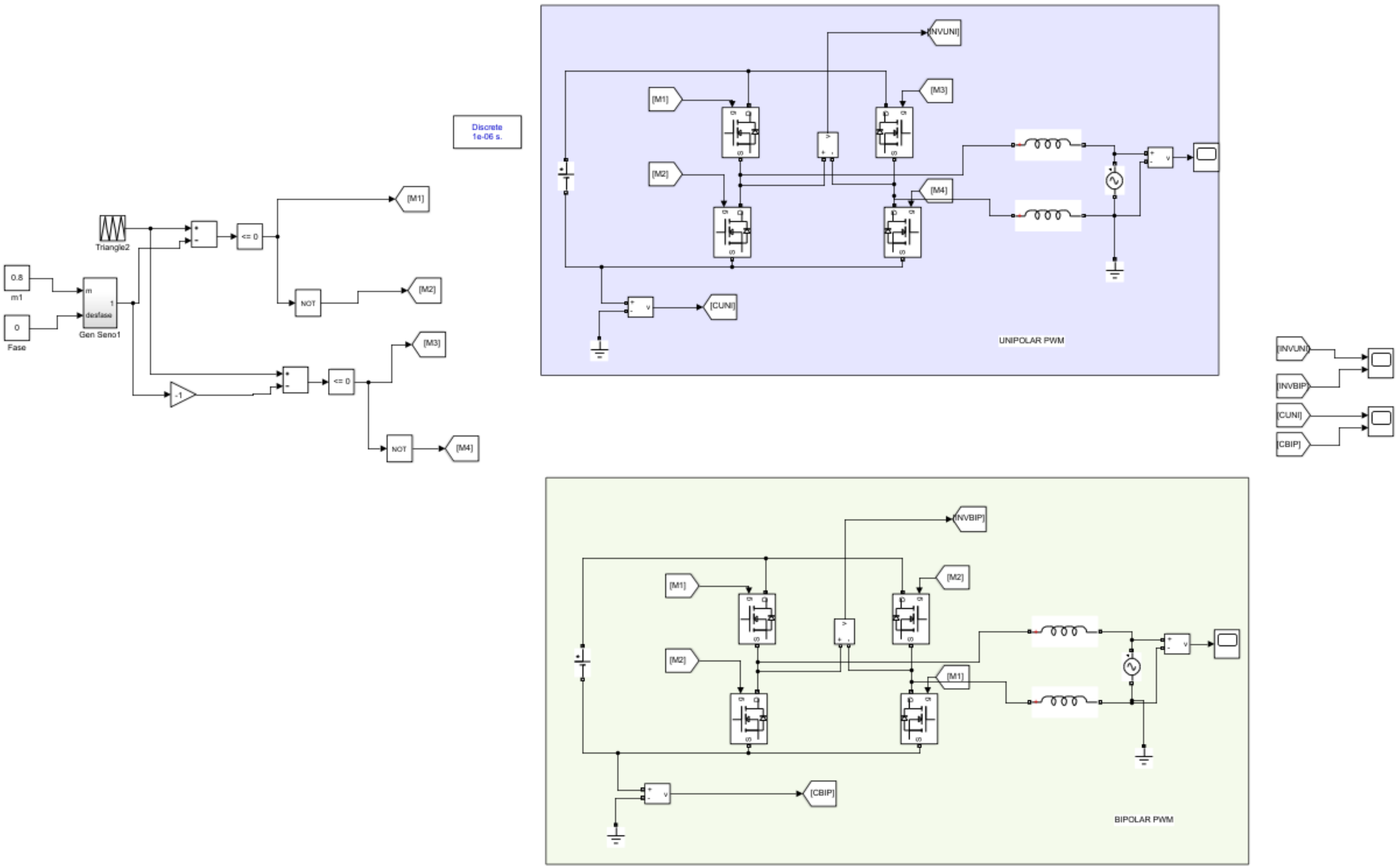

- Positive semi Cycle




- Negative Semi Cycle



# PWM Modulation

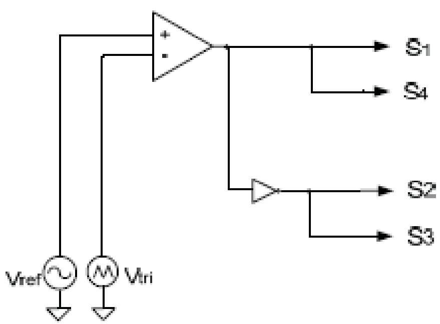



Simulation2 File.

# PWM Modulation

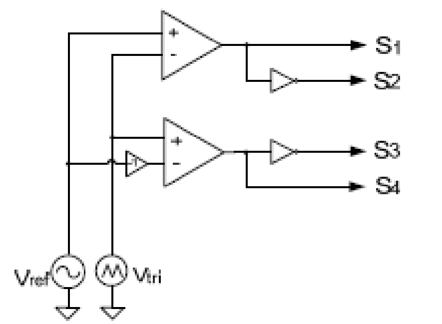
### Bipolar PWM

S1 + S4 and S2 + S3 are switched complementary at high frequency



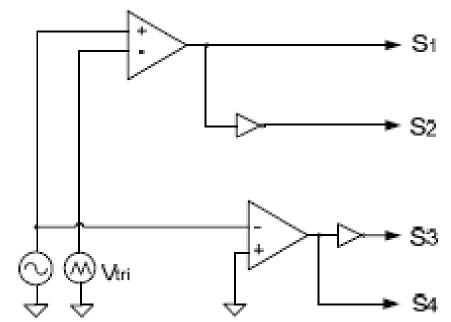

### Unipolar PWM

Leg A and B are switched with high frequency with mirrored sinusoidal ref.

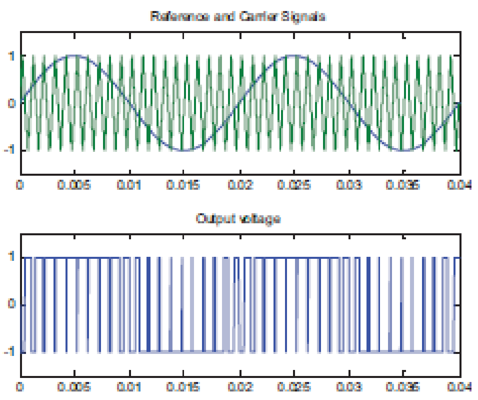



### Hybrid PWM

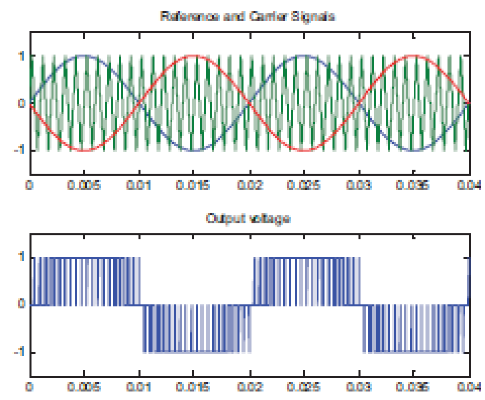
Leg A is switched with high frequency and Leg B is switched with grid frequency



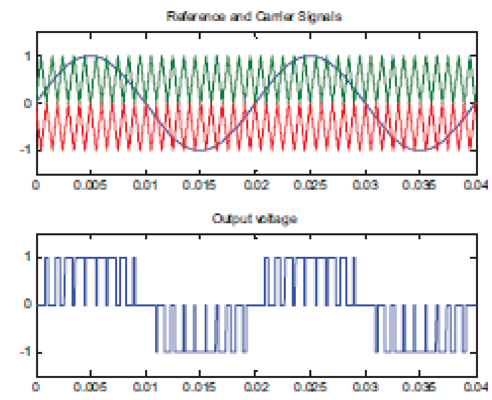

### Bipolar PWM




### Unipolar PWM

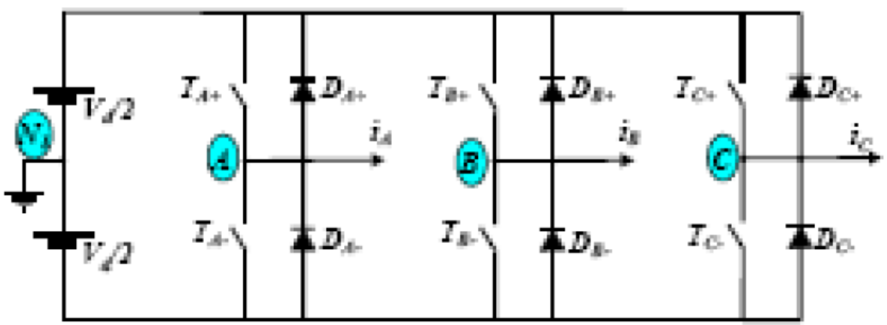



### Hybrid PWM

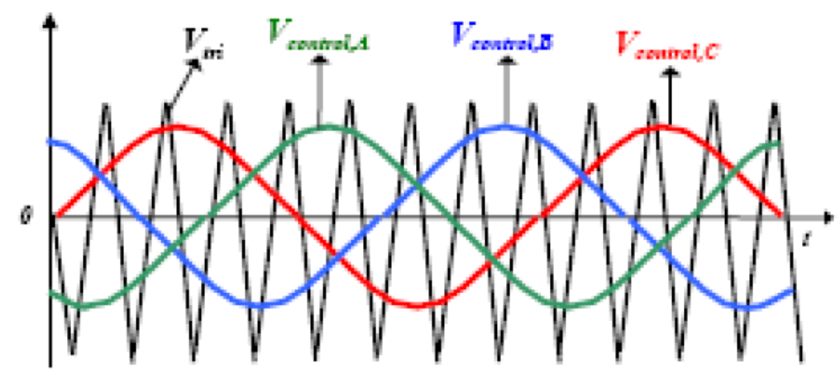


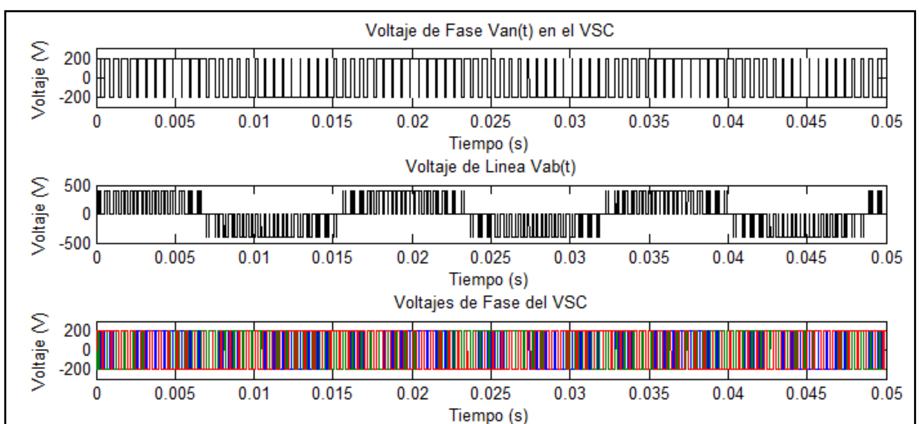
# Three Phase Inverter

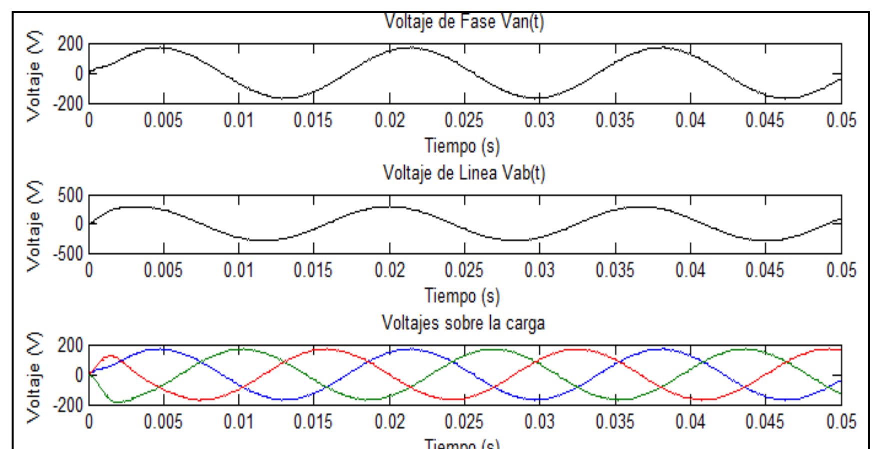
PUENTE TRIFÁSICO




Formas de ondas

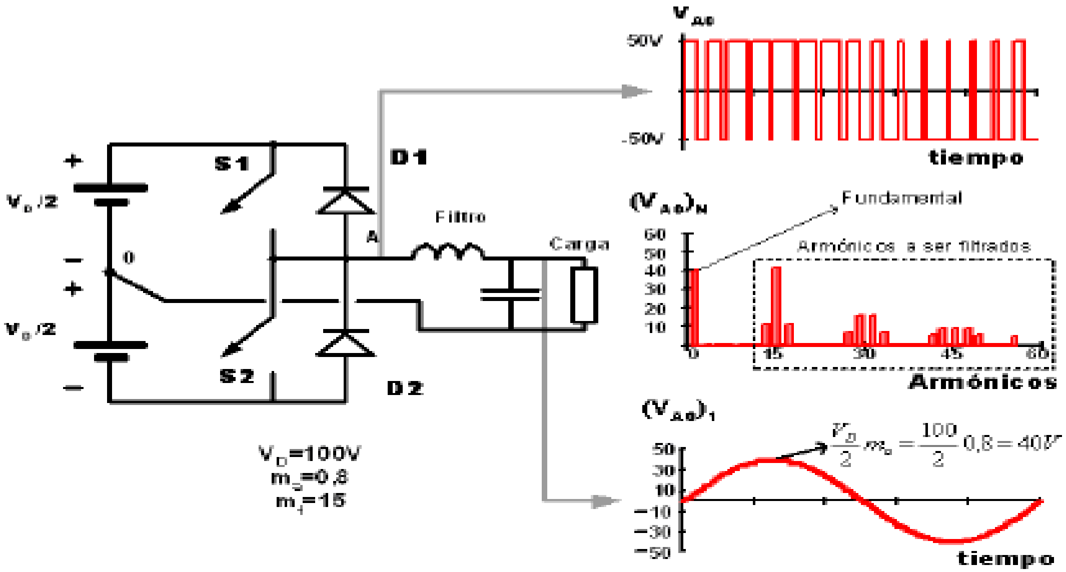


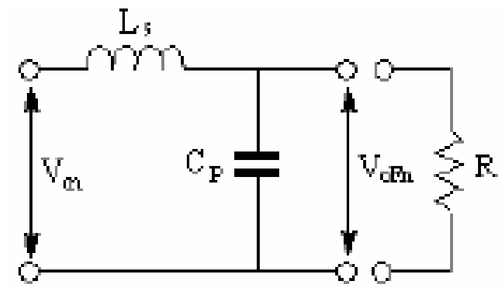




Simulation3 File.

# Filter




$$T_{\text{mod}} \gg \frac{1}{f_{res}} \gg T_c$$

$$f_{\text{mod}} \ll f_{res} \ll f_c$$

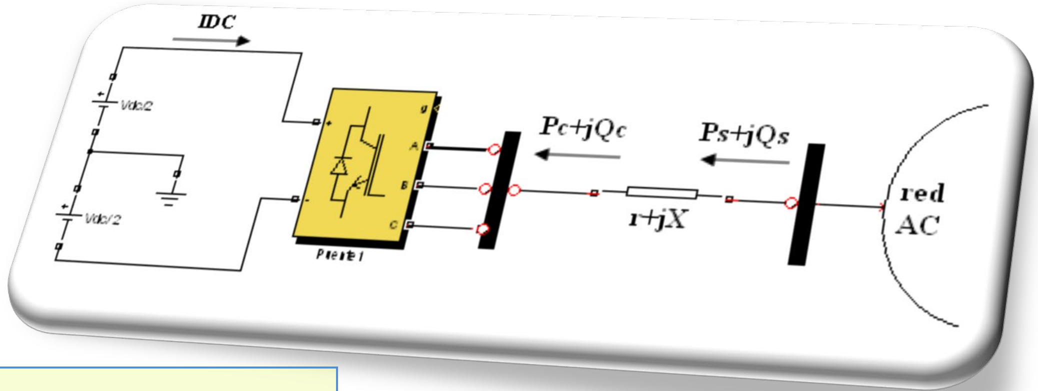
$$\frac{V_{oFn}}{V_{on}} = \frac{L_S + C_p // R}{C_p // R} = \frac{1}{\left(1-\omega^2 CL\right)+\dfrac{j\omega L}{R}}$$

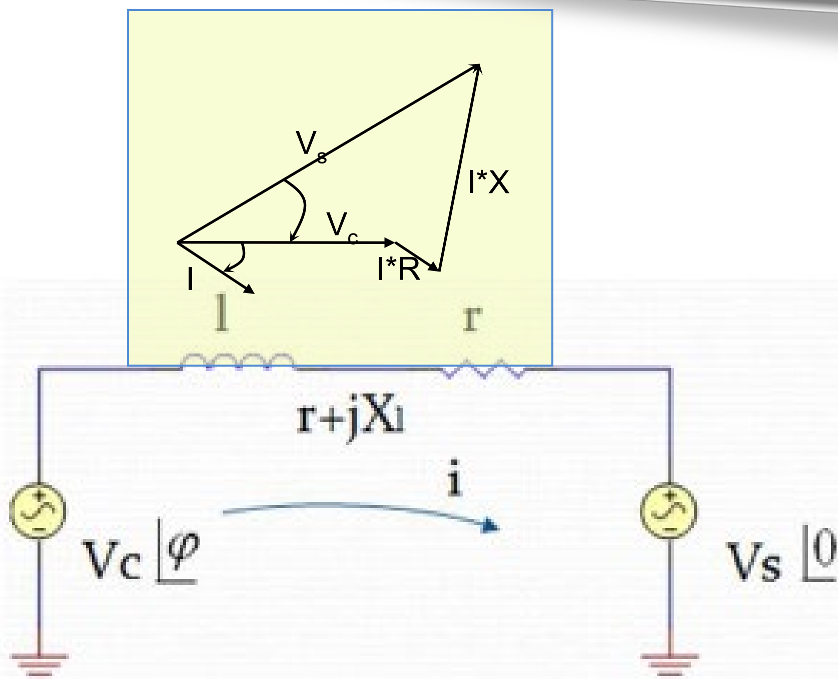
$$f_r = \frac{1}{2\pi\sqrt{L_S \times C_p}}$$

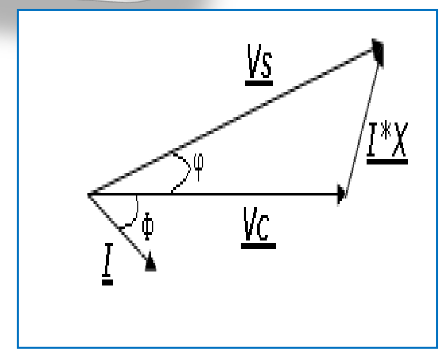
$$Z_{\text{BASE}} = \frac{\left(V_{base}\right)^2}{S_{base}}$$

$$X = 0.2_{\text{PU}} \cdot Z_{\text{BASE}}$$

# 2. Power Inverter.



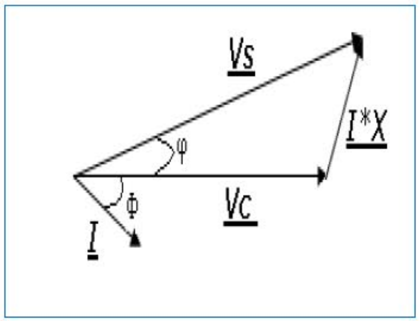




$$P = \frac{V_C \cdot V_S}{X} \sin(\varphi)$$

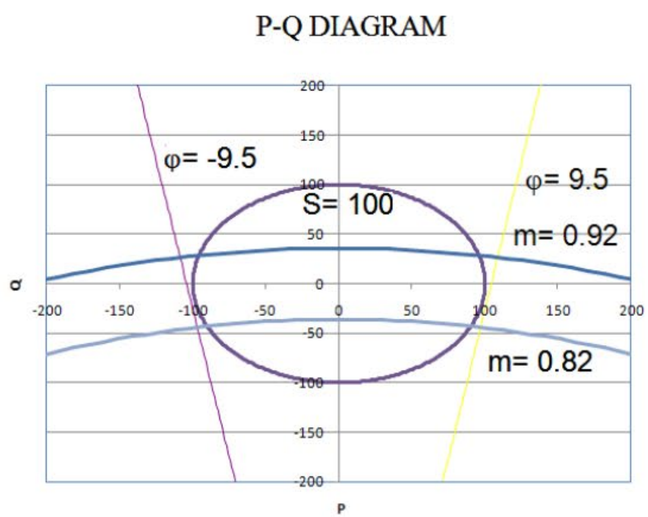
$$Q = \frac{V_S \left( -V_S + V_C \cos(\varphi) \right)}{X}$$

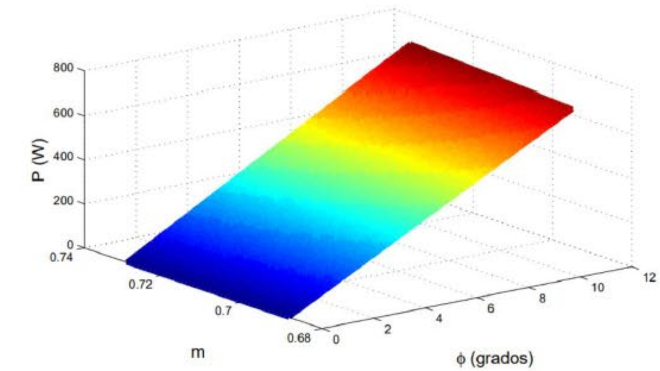
# 2. Power Inverter.

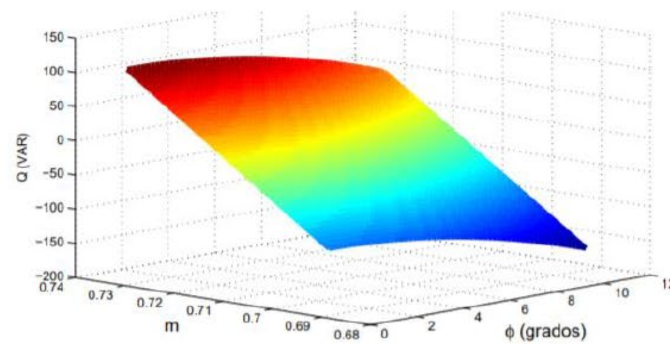



$$P = \frac{V_C \cdot V_S}{X} \sin(\varphi)$$

$$Q = \frac{V_S\left(-V_S + V_C \cos(\varphi)\right)}{X}$$




Simulation4 File.

# Syncronization.

Synchronization is an adaptive process in which an automatic system generates an internal oscillator at the frequency and phase of the system it is interconnecting with.

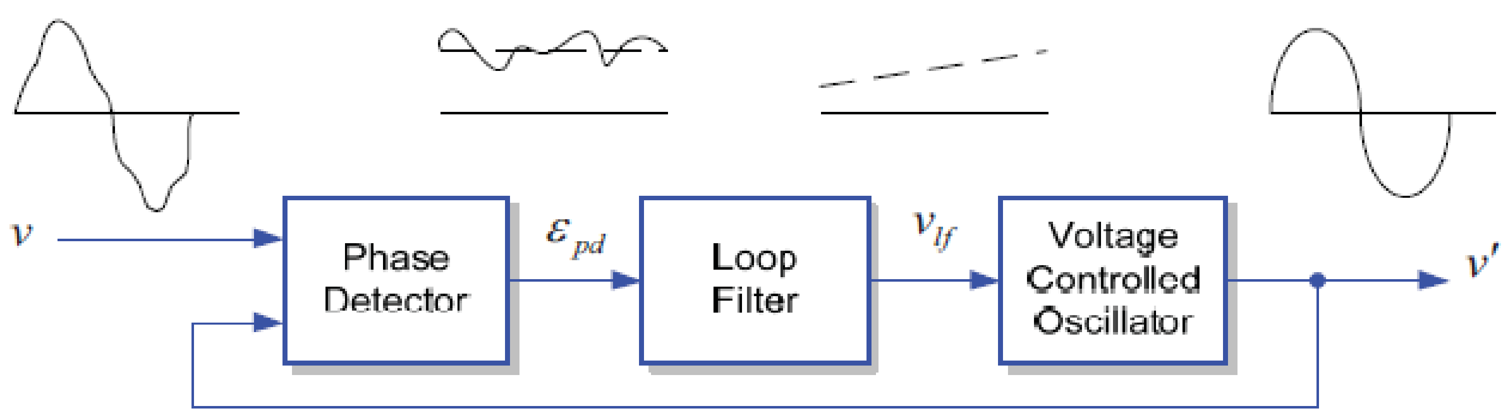
Synchronization handles two main processes:

Frequency tracking.

Phase tracking.

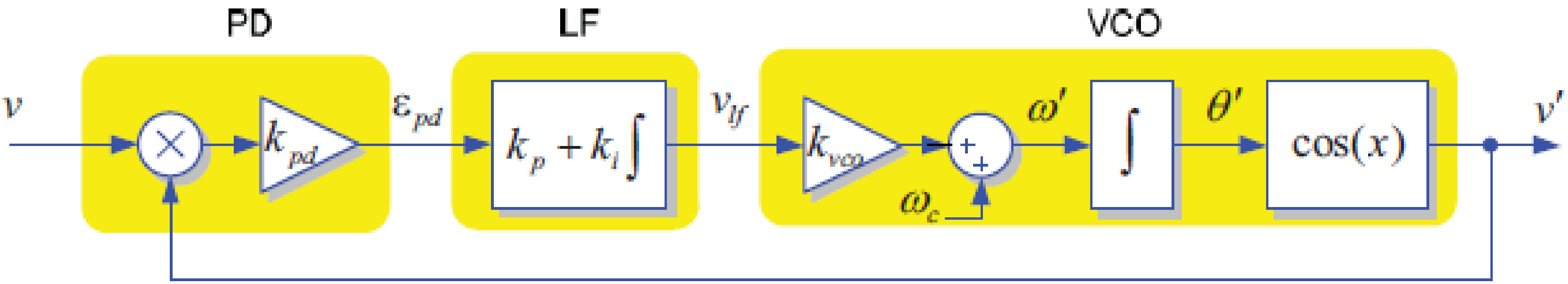
# (Phase Locked Loop) PLL

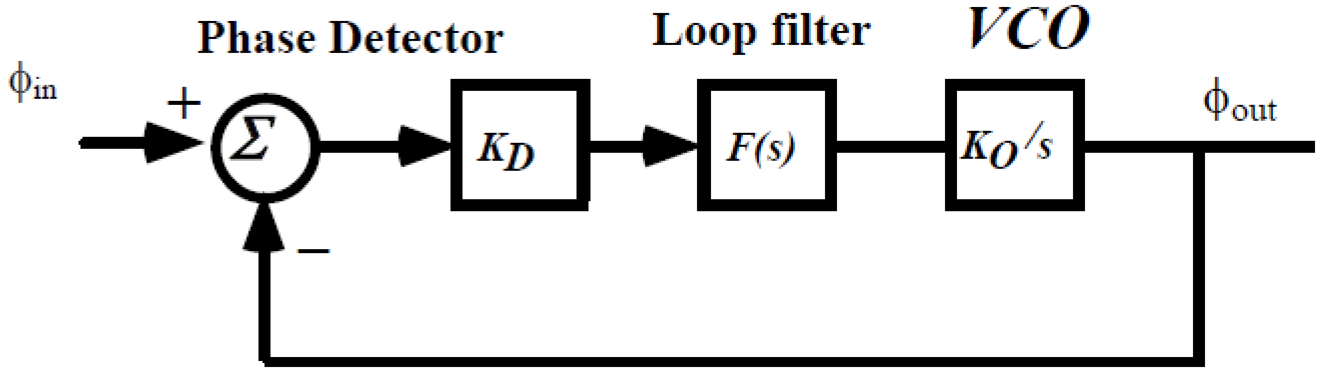
A PLL is a feedback system that includes a phase detector, a low-pass filter, and a voltage-controlled oscillator (VCO). Its main purpose is to compel the VCO to replicate the frequency and phase of the reference within the loop.




Teodorescu, Liserre, Rodriguez, Grid Connected For Fotovoltaic and Wind Power Systems

# (Phase Locked Loop) PLL,

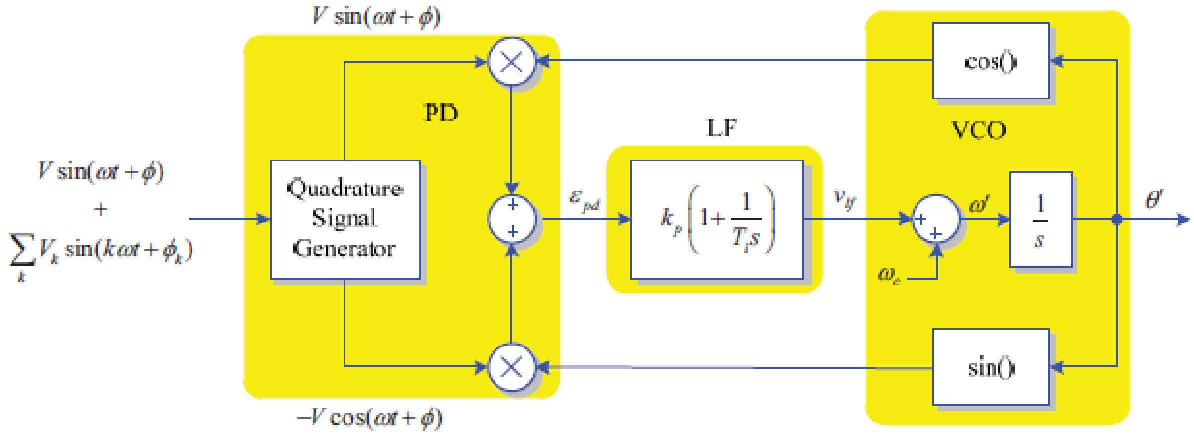



H(s) = T(s)/[1 + T(s)]

$$H(s) = \frac{\phi_{out}}{\phi_{in}} = \frac{K_D K_O F(s)/s}{1 + K_D K_O F(s)/s}$$

# Phase detector based on Quadrature Signal Generator.




- The Quadrature Signal Generator must produce two signals phased 90 degrees apart from a single signal. $v = V\sin(\theta) = V\sin(\omega t+\phi)$

$$\mathbf{v}_{(\alpha\beta)} = \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = V\begin{bmatrix} \sin(\omega t+\phi) \\ -\cos(\omega t+\phi) \end{bmatrix} = V\begin{bmatrix} \sin(\theta) \\ -\cos(\theta) \end{bmatrix}$$

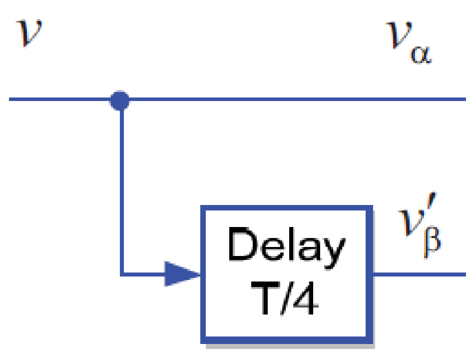
- Then:

$$\varepsilon_{pd} = V\sin(\omega t+\phi)\cos(\omega' t+\phi') - V\cos(\omega t+\phi)\sin(\omega' t+\phi') = V\sin\left((\omega-\omega')t + (\phi-\phi')\right) = V\sin(\theta-\theta')$$

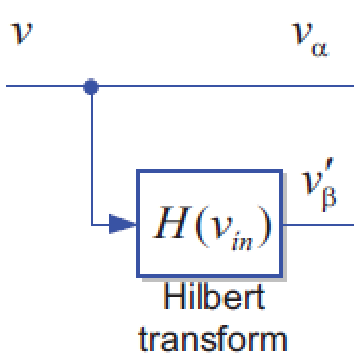
Teodorescu, Liserre, Rodriguez, Grid Connected For Fotovoltaic and Wind Power Systems

# Quadrature Signal Generators

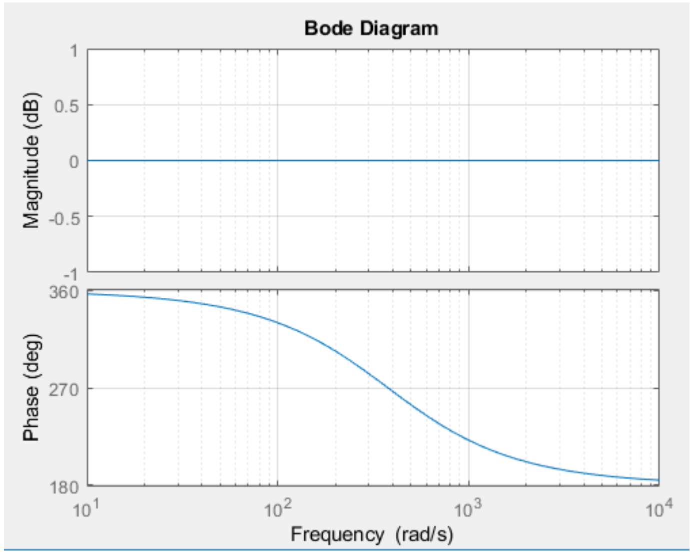
- T/4 Delay




- Tuned Filter




$$H(v_{in}) = \frac{\omega_0 - s}{\omega_0 + s}$$



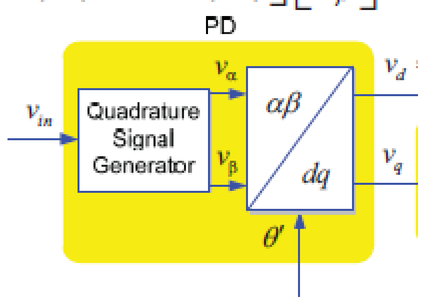
# Park Transformation

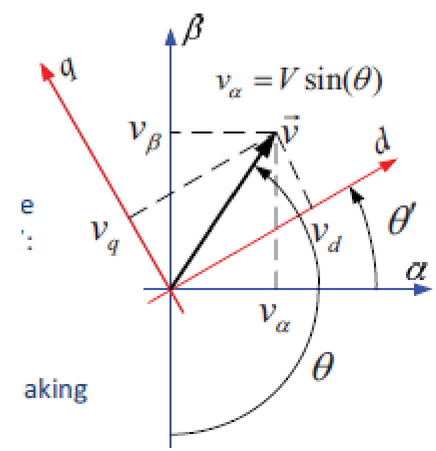
- Once we have the pase a quadrature signals:

$$\mathbf{v}_{(\alpha\beta)} = \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = V \begin{bmatrix} \sin(\theta) \\ -\cos(\theta) \end{bmatrix}$$

- The Park Transformation allows transforming time-varying signals into constant signals in a synchronous reference frame (SRF):

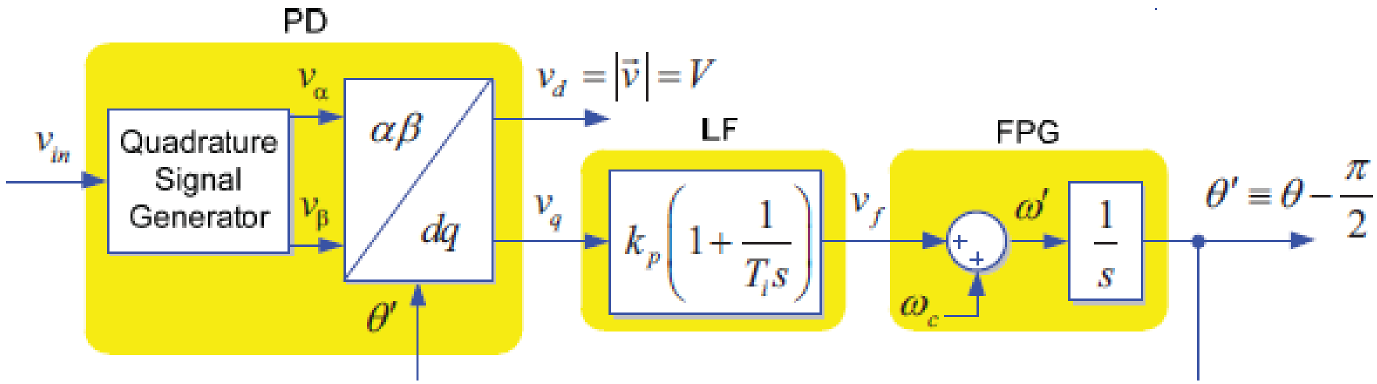
$$\mathbf{v}_{(dq)} = \begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} \cos(\theta') & \sin(\theta') \\ -\sin(\theta') & \cos(\theta') \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = V \begin{bmatrix} \sin(\theta - \theta') \\ -\cos(\theta - \theta') \end{bmatrix}$$

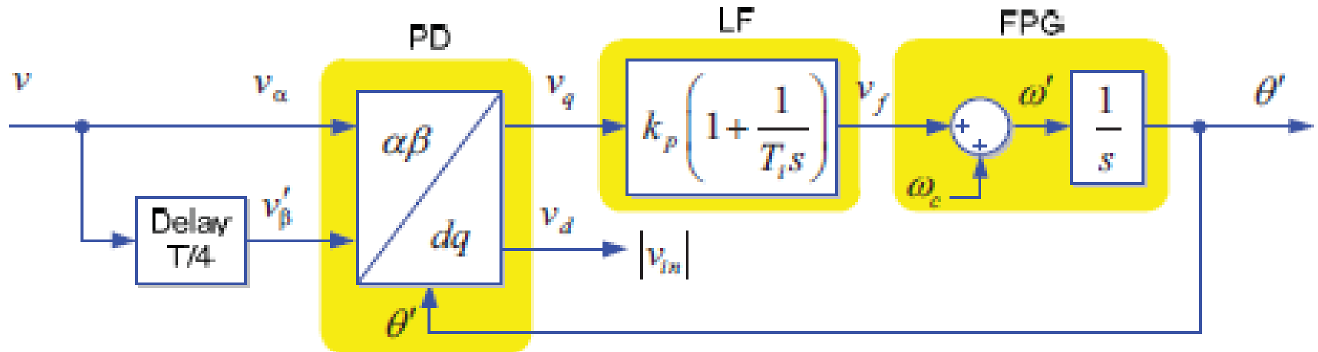



Teodorescu, Liserre, Rodriguez, Grid Connected For Fotovoltaic and Wind Power Systems

# SRF PLL

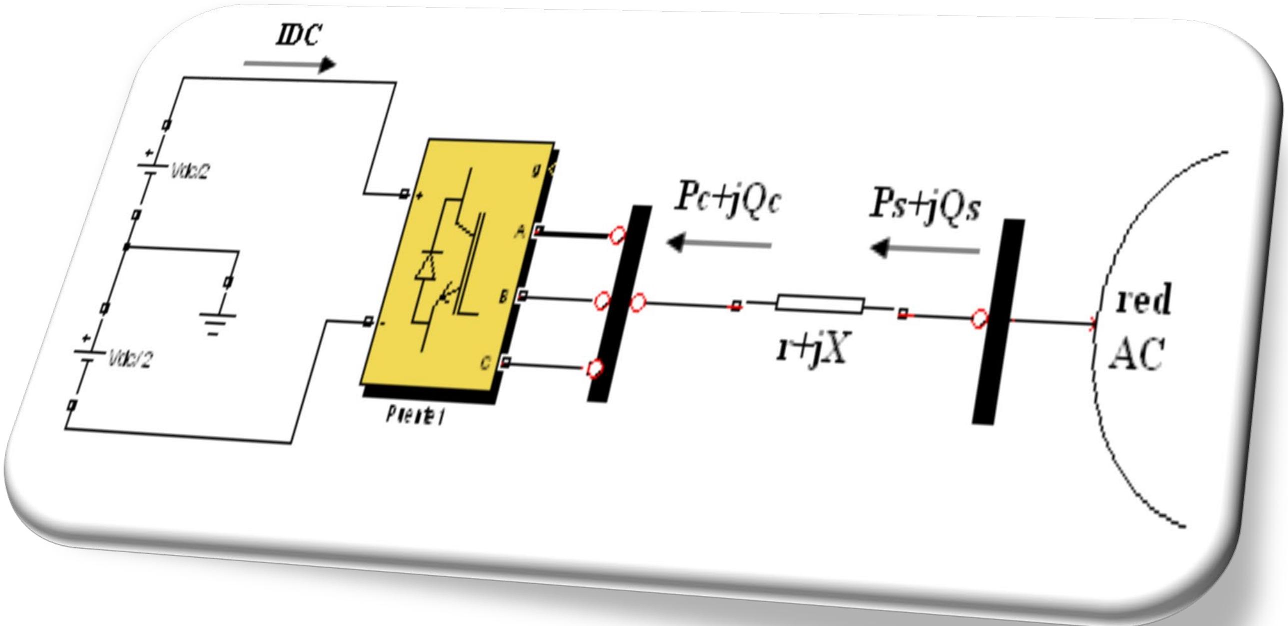



Teodorescu, Liserre, Rodriguez, Grid Connected For Fotovoltaic and Wind Power Systems

# 2. Power Inverter.

## Excersice




Simulation2, 4, 5 File.

# Control and Topological Operation

## Inner Control Loops

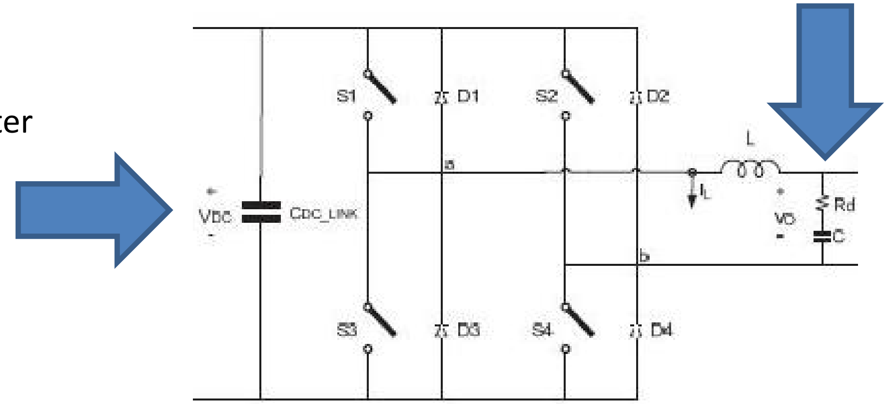
- **Grid Forming Controls:**
  - Voltage Control. (VCM).
  - Frequency.
  - Power Sharing.

- **Grid-Following Controls:**
  - Curent Control (CCM)
  - Power Export.
  - Power Dispatch.
  - Reactive power support

# Inner Control Loops

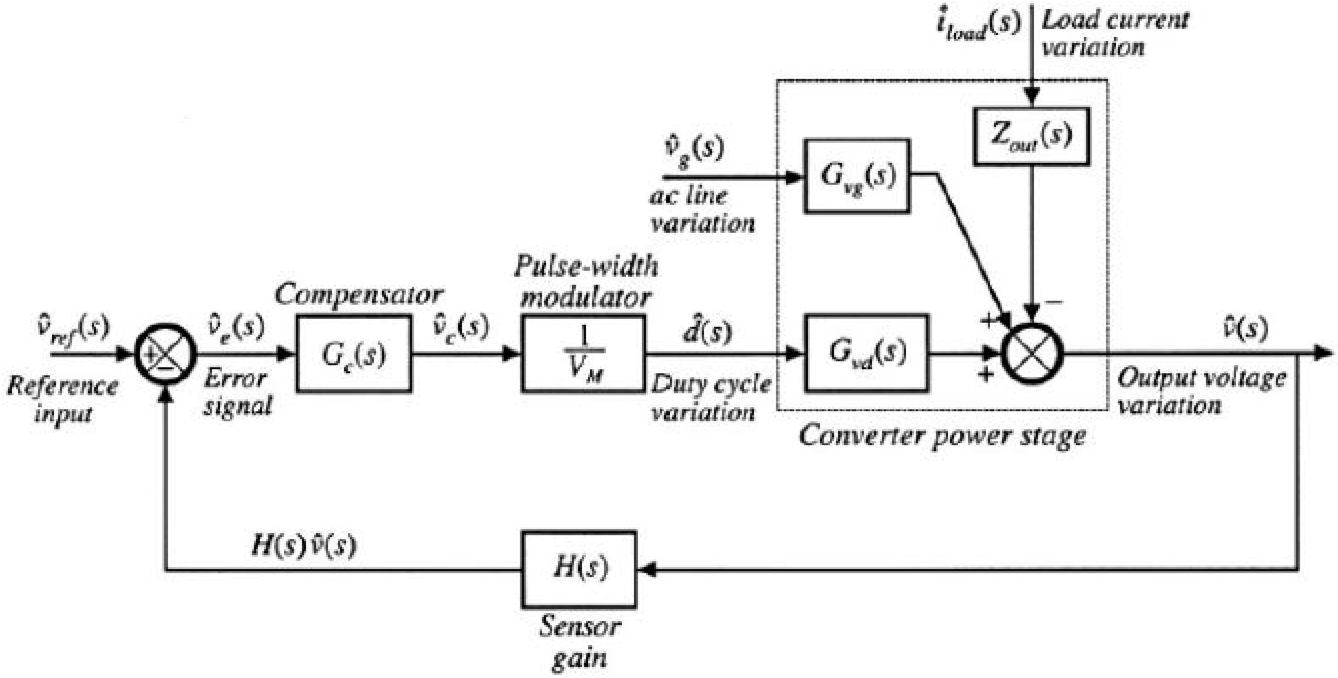
AC side Filter

DC side Filter




***The Dynamic response depends mainly on the AC and DC Filters.***

# 2. Power Converter.

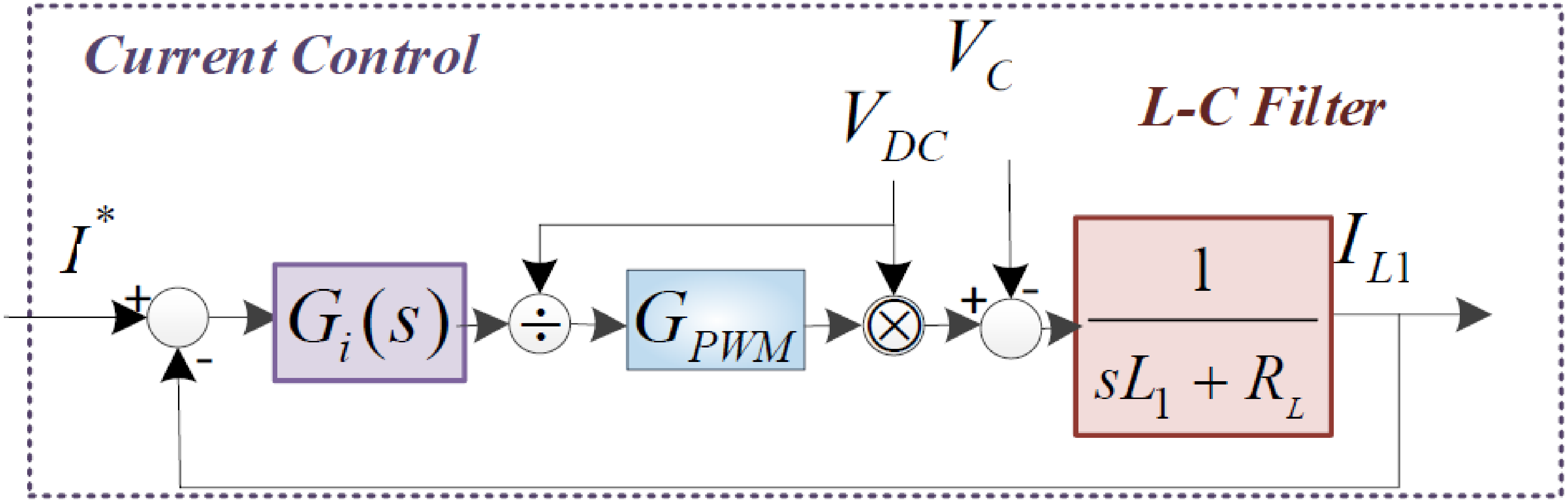



$$\hat{v}(s) = \hat{v_{ref}}(s)\frac{1}{H(s)}\frac{T(s)}{1+T(s)} + \frac{\hat{v_g}(s)}{1+T(s)} - \frac{\hat{i}_{Load}}{1+T(s)}$$

***Once the Dynamic model is defined The negative feedback Control loop Will make the system to follows the reference***

**Erickson Fundamentals of power electronics**

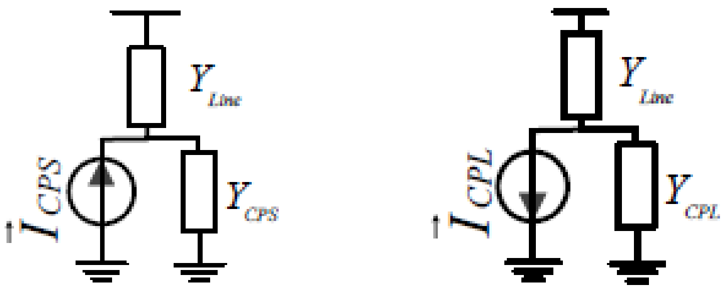
# 2. Power Converter.

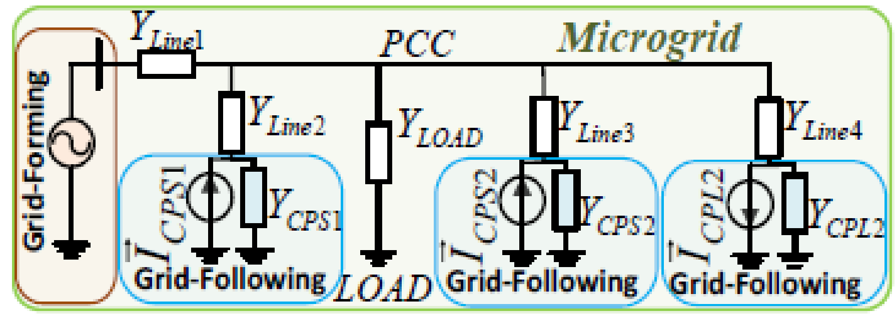


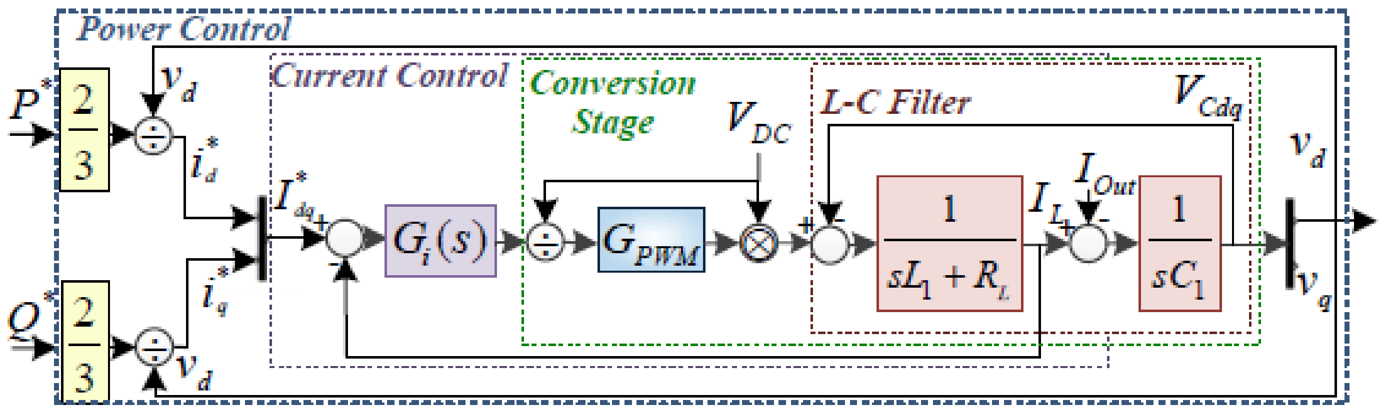

Simulation6 File.

# Grid-Following

Grid-Following



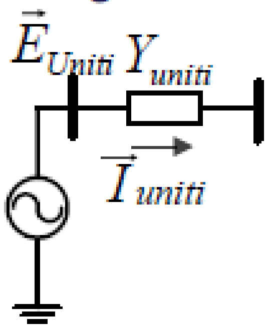

## Current Control Mode (CCM)

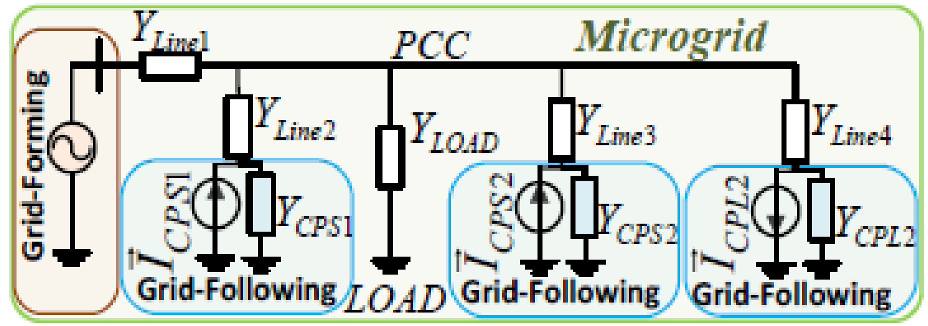
Simulation7 File.

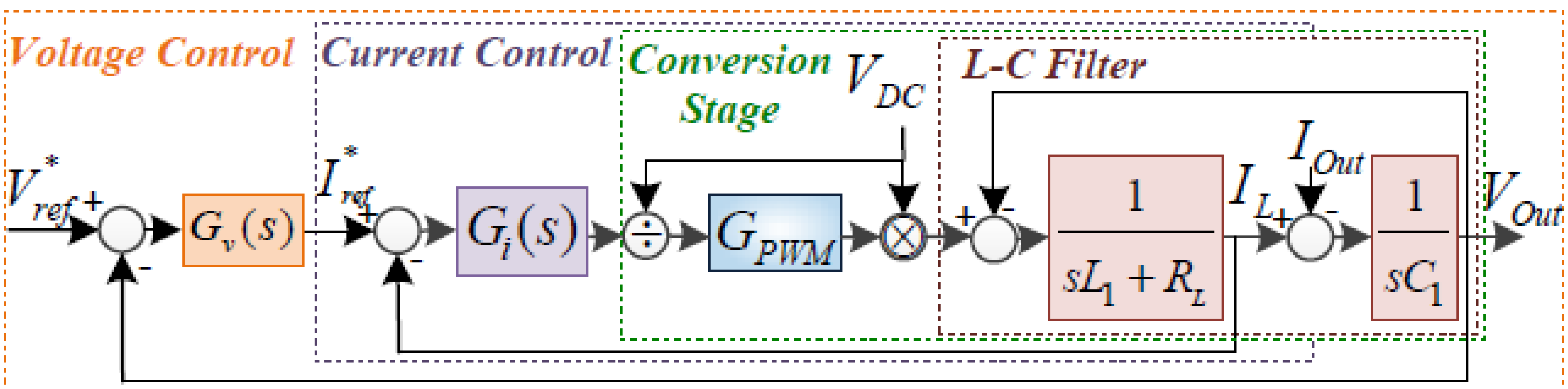
# 2. Power Converter.

## Grid-Forming

Grid-Forming



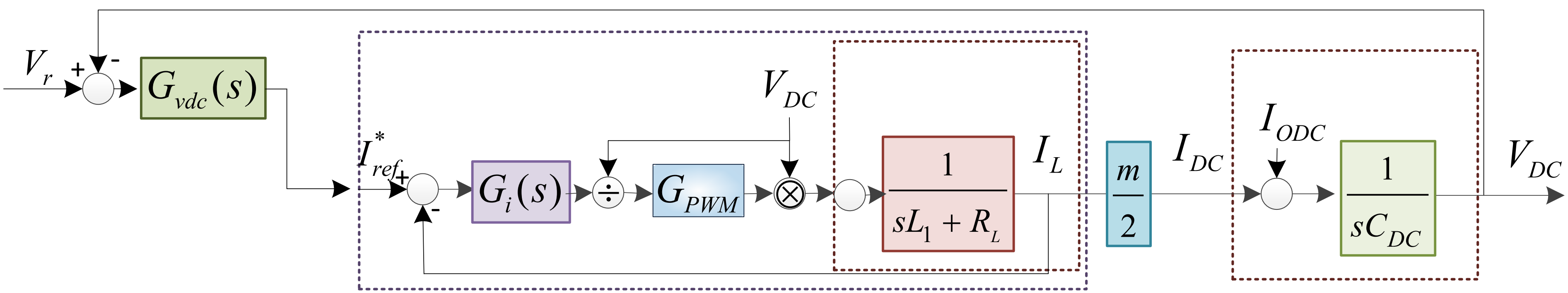




## Voltage Control Mode (VCM)

Simulation8 File.

# DC Voltage Control



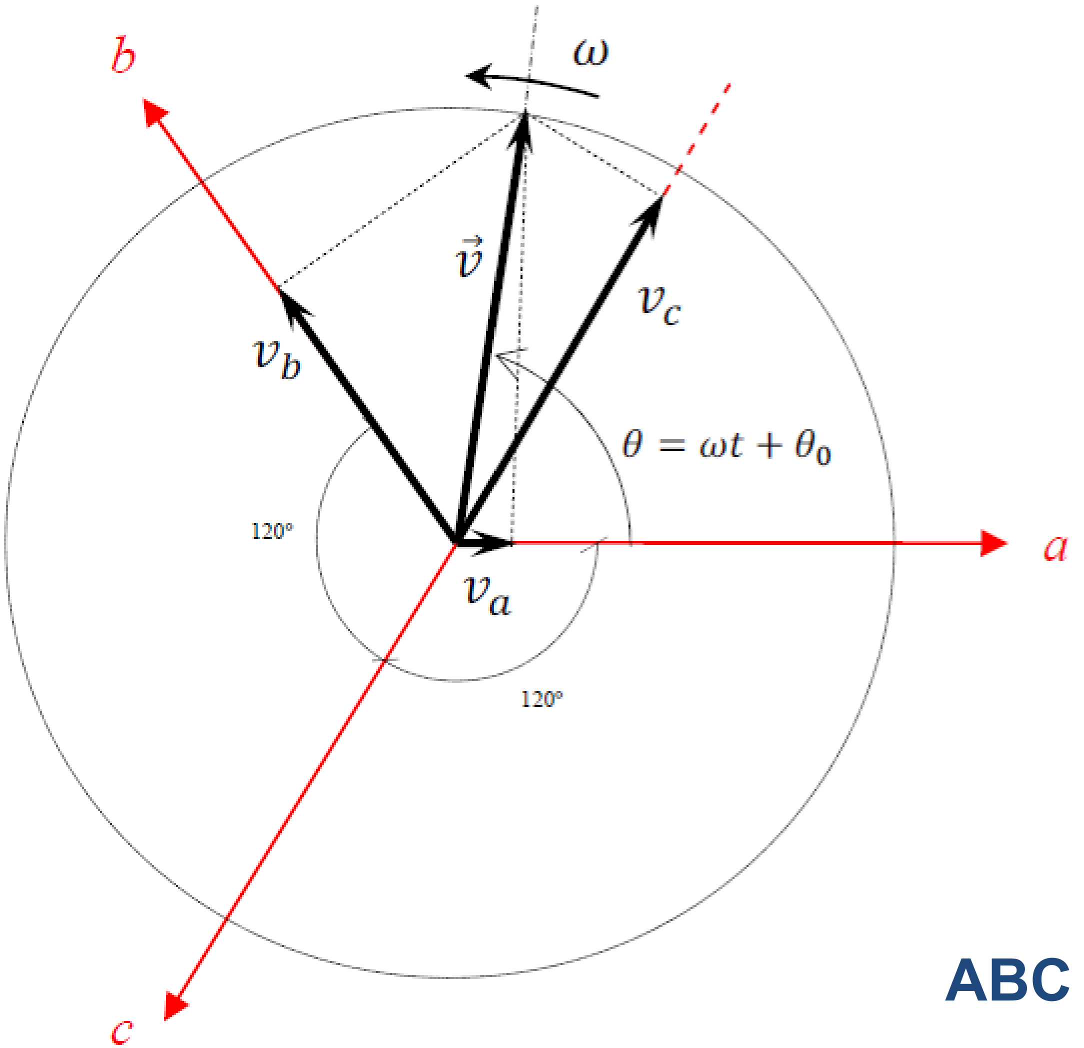

Simulation8 File.

# Three Phase Inverter Control

The question is:

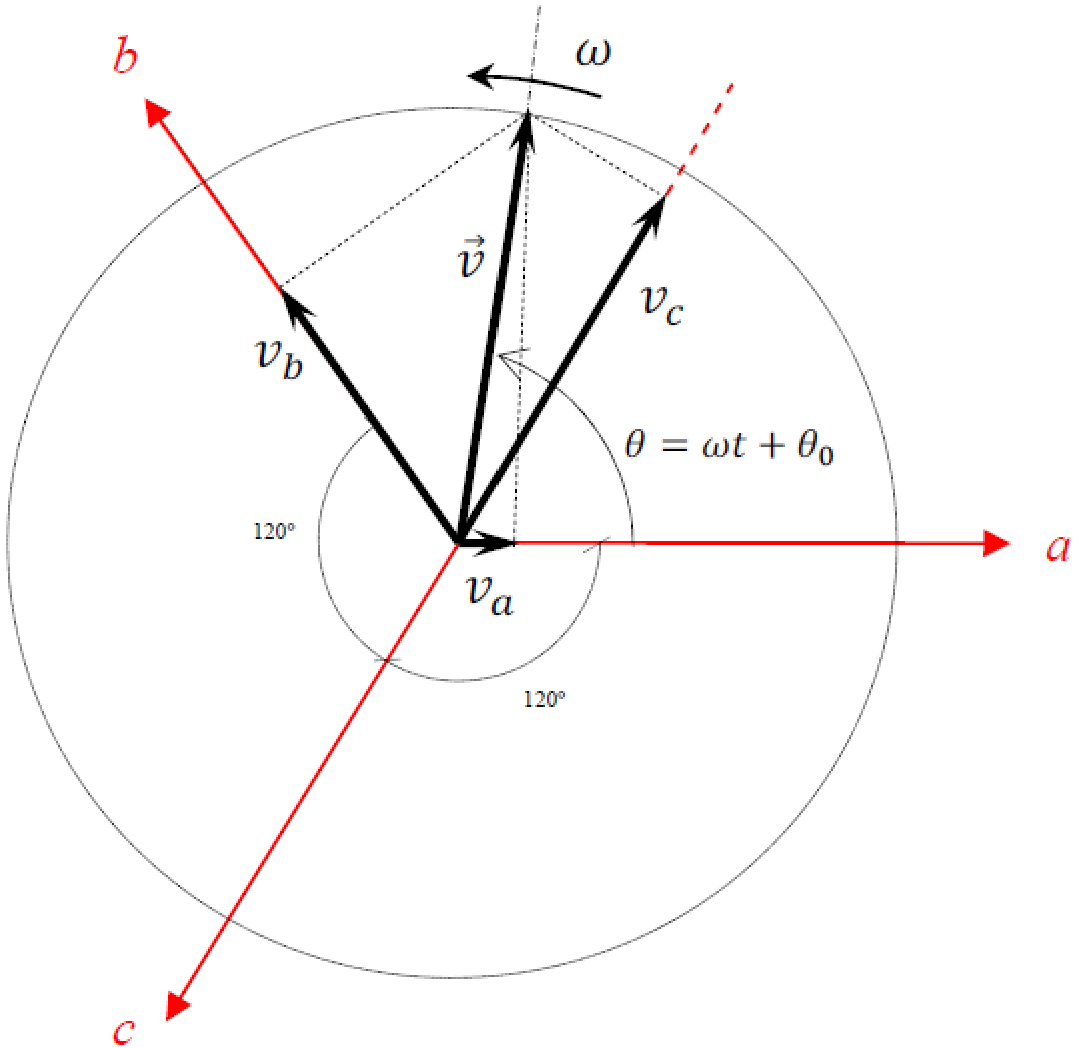
Is it necessary to have a contro lopp per pase in a Three pase system?

# 2. Power Converter.

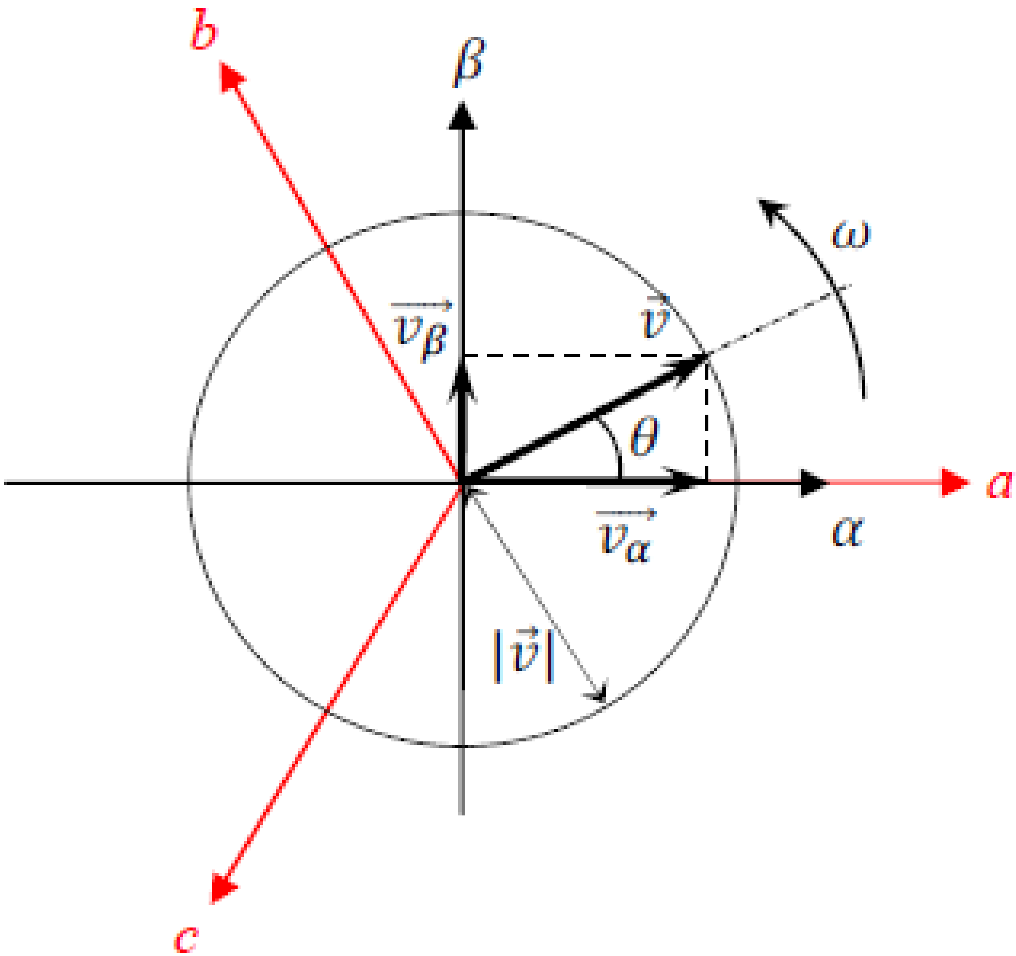



**ABC**

# 2. Power Converter.



## ABC-αβ



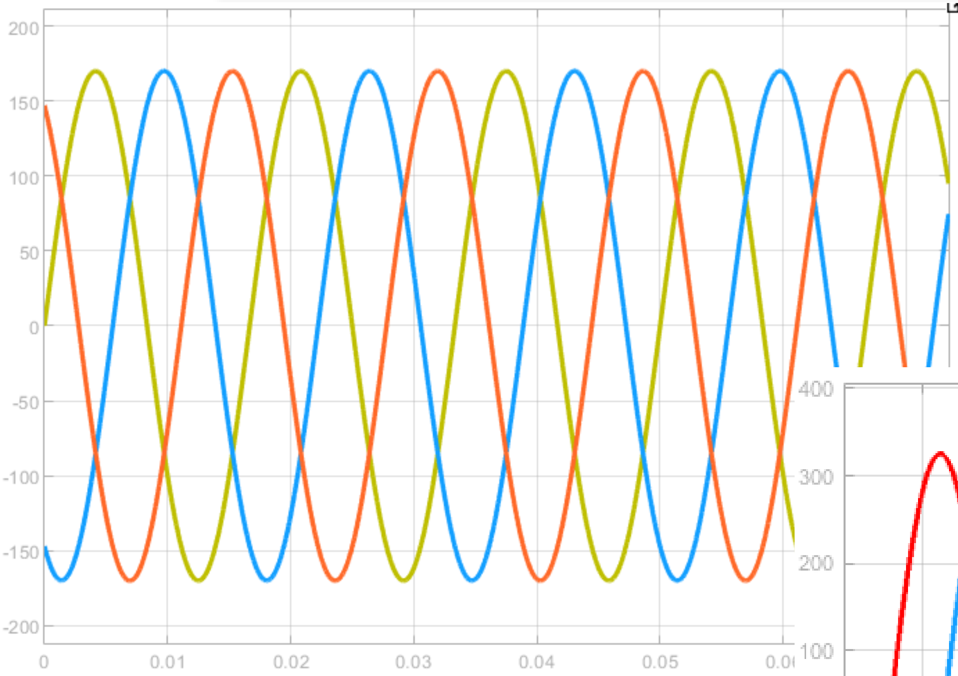

$$v_{abc} = \begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} = v_m \begin{pmatrix} \cos(\theta) \\ \cos(\theta - {}^{2\pi}/_{3}) \\ \cos(\theta + {}^{2\pi}/_{3}) \end{pmatrix}$$

$$\theta = \omega t + \theta_0$$

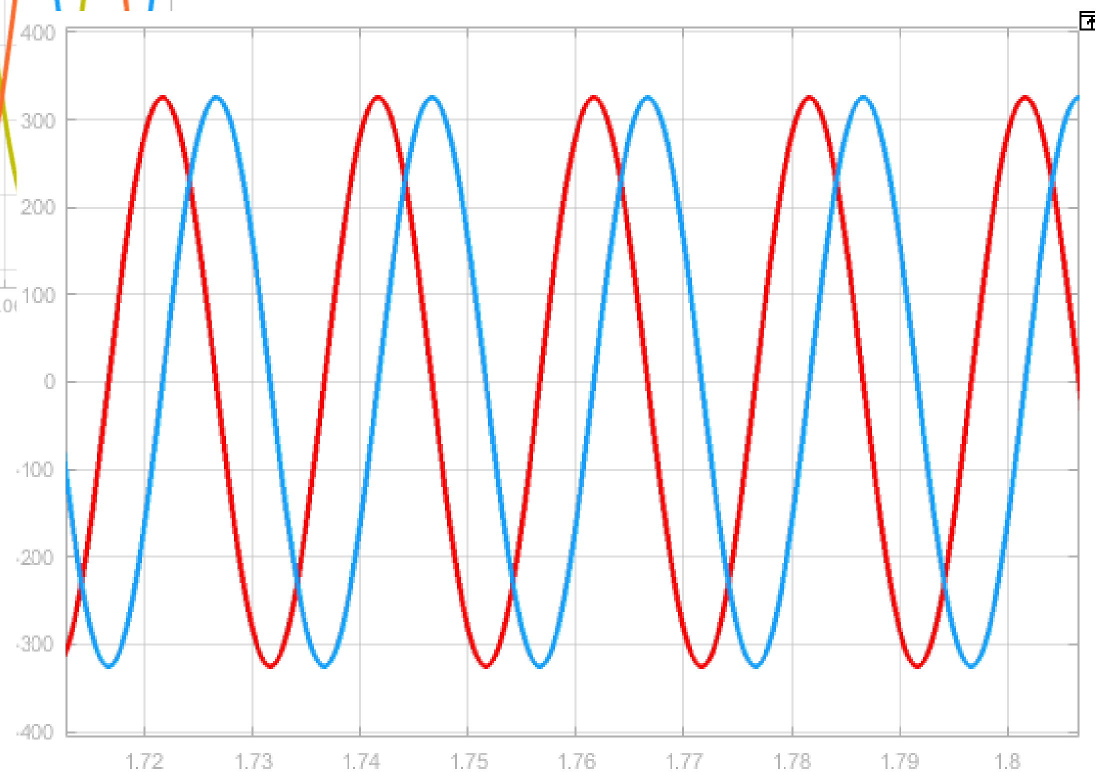
$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = [Clarke\ Matrix] \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = K \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

# 2. Power Converter.




$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = K \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$




**ABC-αβ**

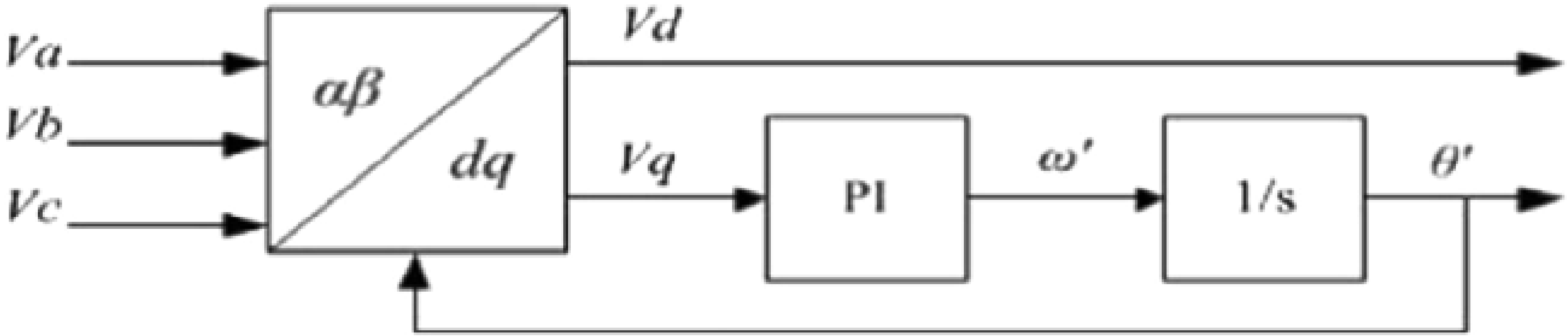
# 2. Power Converter.

| Cte. | Transf. | Inversa | Potencia instantánea trifásica: $p(t)$ | Potencia instantánea trifásica: $q(t)$ | Escalado |
|---|---|---|---|---|---|
| $\sqrt{2/3}$ | T.Clarke | $T^{-1} = T^t$ | $p = v_\alpha i_\alpha + v_\beta i_\beta$ | $q = v_\beta i_\alpha - v_\alpha i_\beta$ | $\sqrt{2/3}$ |
| | T.Park | $T^{-1} = T^t$ | $p = v_d i_d + v_q i_q$ | $q = v_q i_d - v_d i_q$ | $\sqrt{2/3}$ |
| $2/3$ | T.Clarke | $T^{-1} = \frac{3}{2} T^t$ | $p = \frac{3}{2}(v_\alpha i_\alpha + v_\beta i_\beta)$ | $q = \frac{3}{2}(v_\beta i_\alpha - v_\alpha i_\beta)$ | 1 |
| | T.Park | $T^{-1} = \frac{3}{2} T^t$ | $p = \frac{3}{2}(v_d i_d + v_q i_q)$ | $q = \frac{3}{2}(v_q i_d - v_d i_q)$ | 1 |
| 1 | T.Clarke | $T^{-1} = \frac{2}{3} T^t$ | $p = \frac{2}{3}(v_\alpha i_\alpha + v_\beta i_\beta)$ | $q = \frac{2}{3}(v_\beta i_\alpha - v_\alpha i_\beta)$ | 3/2 |
| | T.Park | $T^{-1} = \frac{2}{3} T^t$ | $p = \frac{2}{3}(v_d i_d + v_q i_q)$ | $q = \frac{2}{3}(v_q i_d - v_d i_q)$ | 3/2 |

Same Power Value in αβ and abc

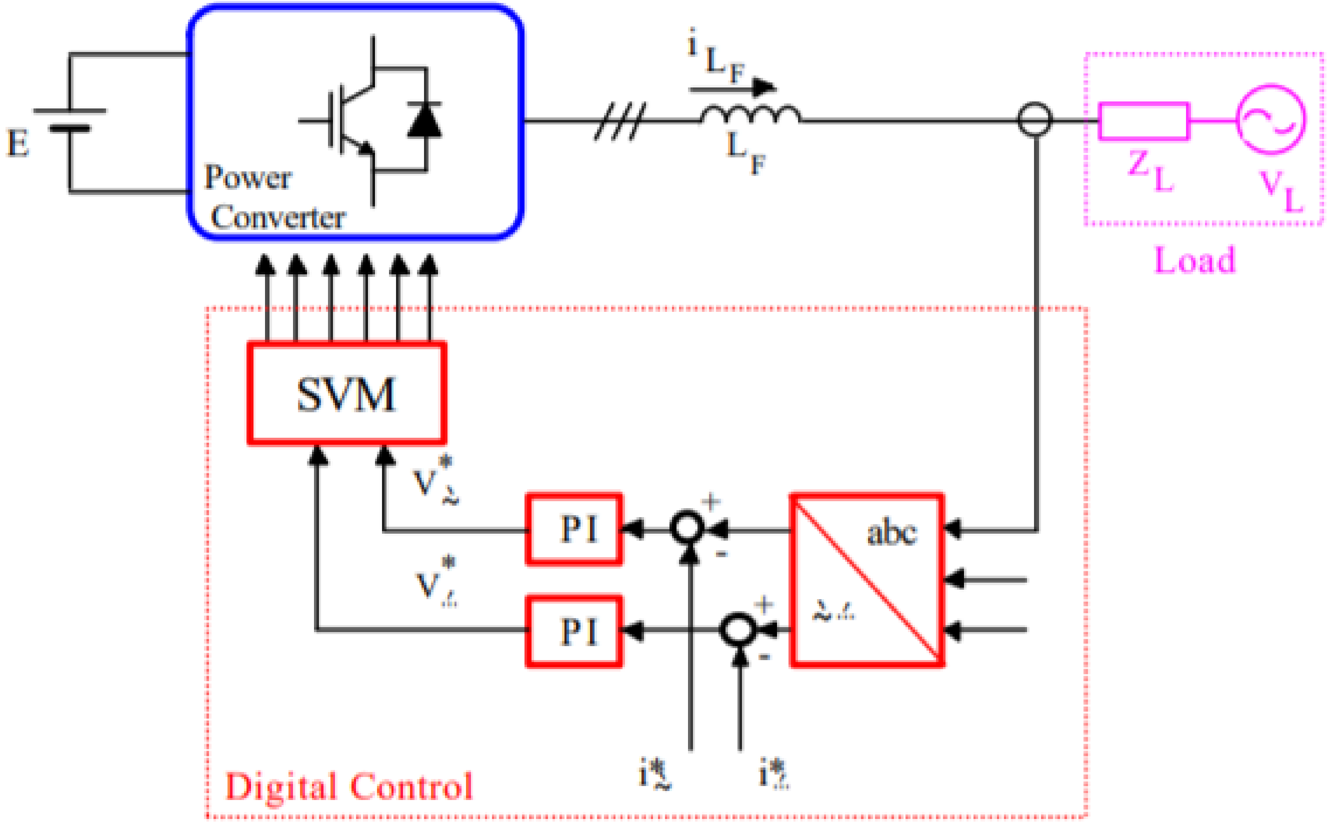
Same voltaje and current value in αβ and abc

## PLL



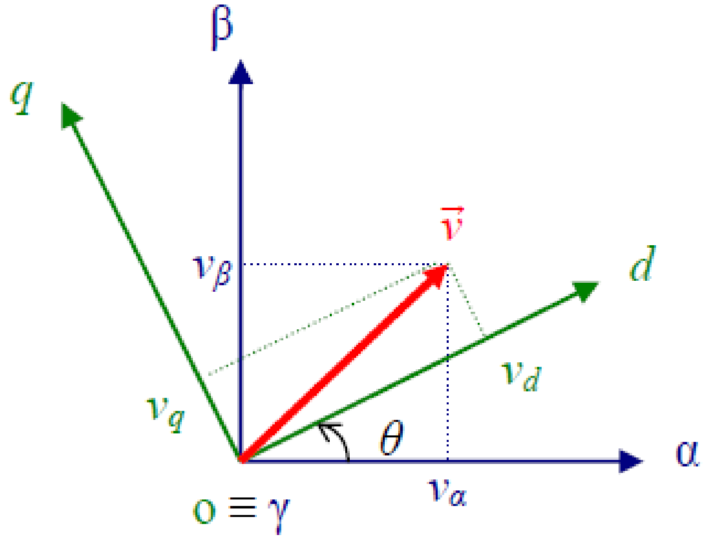
# 2. Power Converter.

## αβ Control




Simulation8 File.

## αβ-DQ



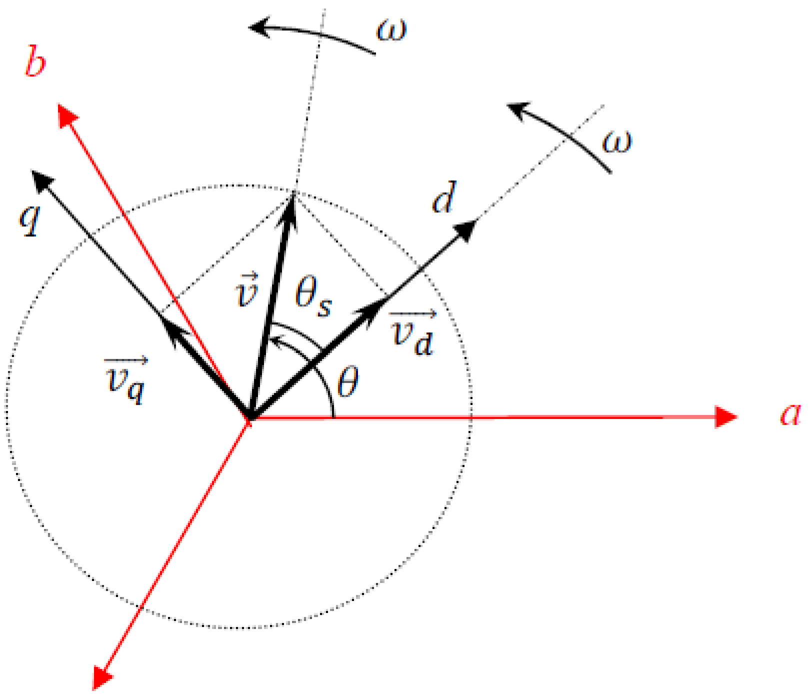

$$\begin{bmatrix} d \\ q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \times \begin{bmatrix} \alpha \\ \beta \end{bmatrix}$$

$$\begin{bmatrix} d \\ q \end{bmatrix} = [Park\ Matrix] \times \begin{bmatrix} \alpha \\ \beta \end{bmatrix}$$

$$\begin{bmatrix} d \\ q \end{bmatrix} = [Park\ Matrix] \times [Clarke\ Matrix] \times \begin{bmatrix} \mathbf{A} \\ \mathbf{B} \\ \mathbf{C} \end{bmatrix}$$

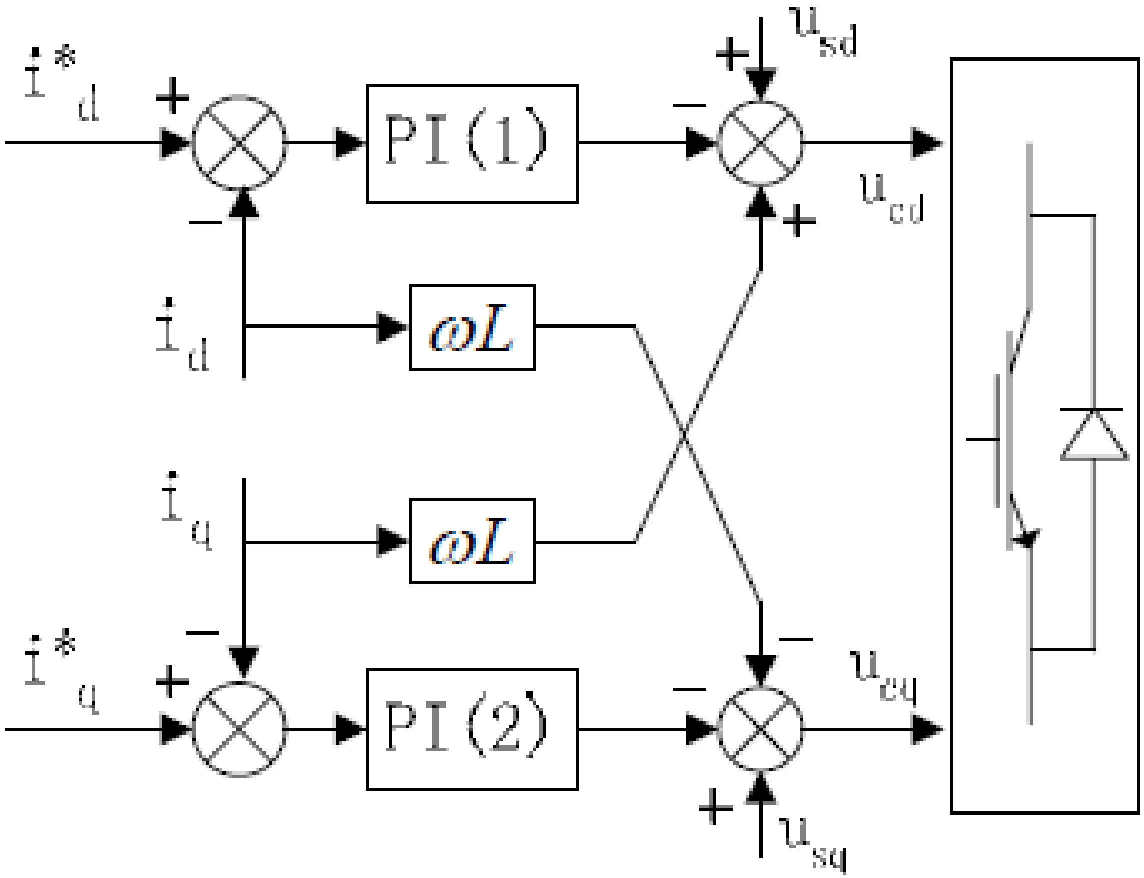
# 2. Power Converter.

## ABC-DQ




$$\begin{bmatrix} f_d \\ f_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\omega t) & \cos(\omega t - \frac{2}{3}\pi) & \cos(\omega t + \frac{2}{3}\pi) \\ -\sin(\omega t) & -\sin(\omega t - \frac{2}{3}\pi) & -\sin(\omega t + \frac{2}{3}\pi) \end{bmatrix} \cdot \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix}$$

## DQ-Control



# In a Three pase system we need three signals for the SPWM. What to do?

$$\delta_{an}(t) = \frac{1}{2} + \frac{1}{2} m * \sin(\omega t + \varphi)$$

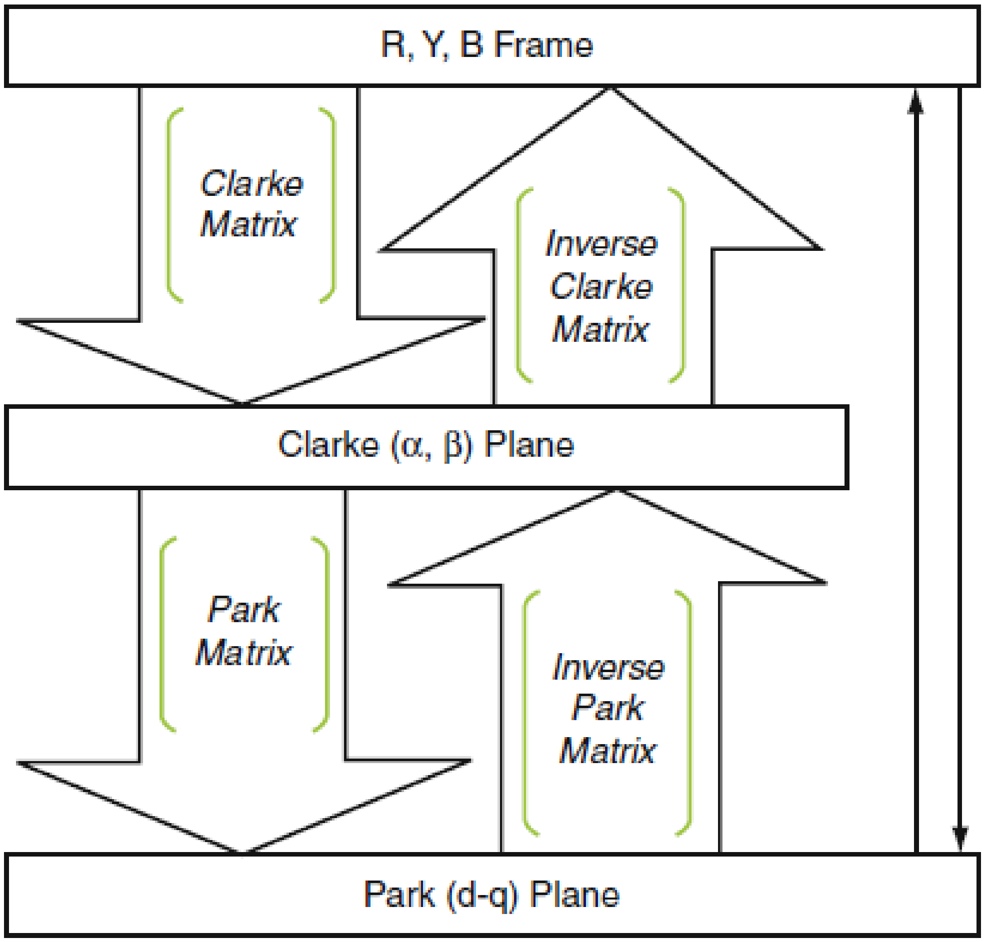
$$\delta_{bn}(t) = \frac{1}{2} + \frac{1}{2} m * \sin\left(\omega t - \frac{2\pi}{3} + \varphi\right)$$

$$\delta_{cn}(t) = \frac{1}{2} + \frac{1}{2} m * \sin(\omega t + 2\pi/3 + \varphi)$$

***Inverse transformation***

# 2. Power Converter.

## ABC-αβ-DQ- αβ-ABC



## Inverse Tranformation

$$[T]\cdot[T]^T = \sqrt{\frac{2}{3}}\cdot T\cdot\sqrt{\frac{2}{3}}\cdot T^T = \frac{2}{3}\cdot T\cdot T^T = [I]_{3\times 3} \qquad \Rightarrow \qquad [T]^T = [T]^{-1}$$

$$\begin{bmatrix}\alpha\\ \beta\end{bmatrix} = [Inverse\ Park\ Matrix]\times\begin{bmatrix}d\\ q\end{bmatrix}$$

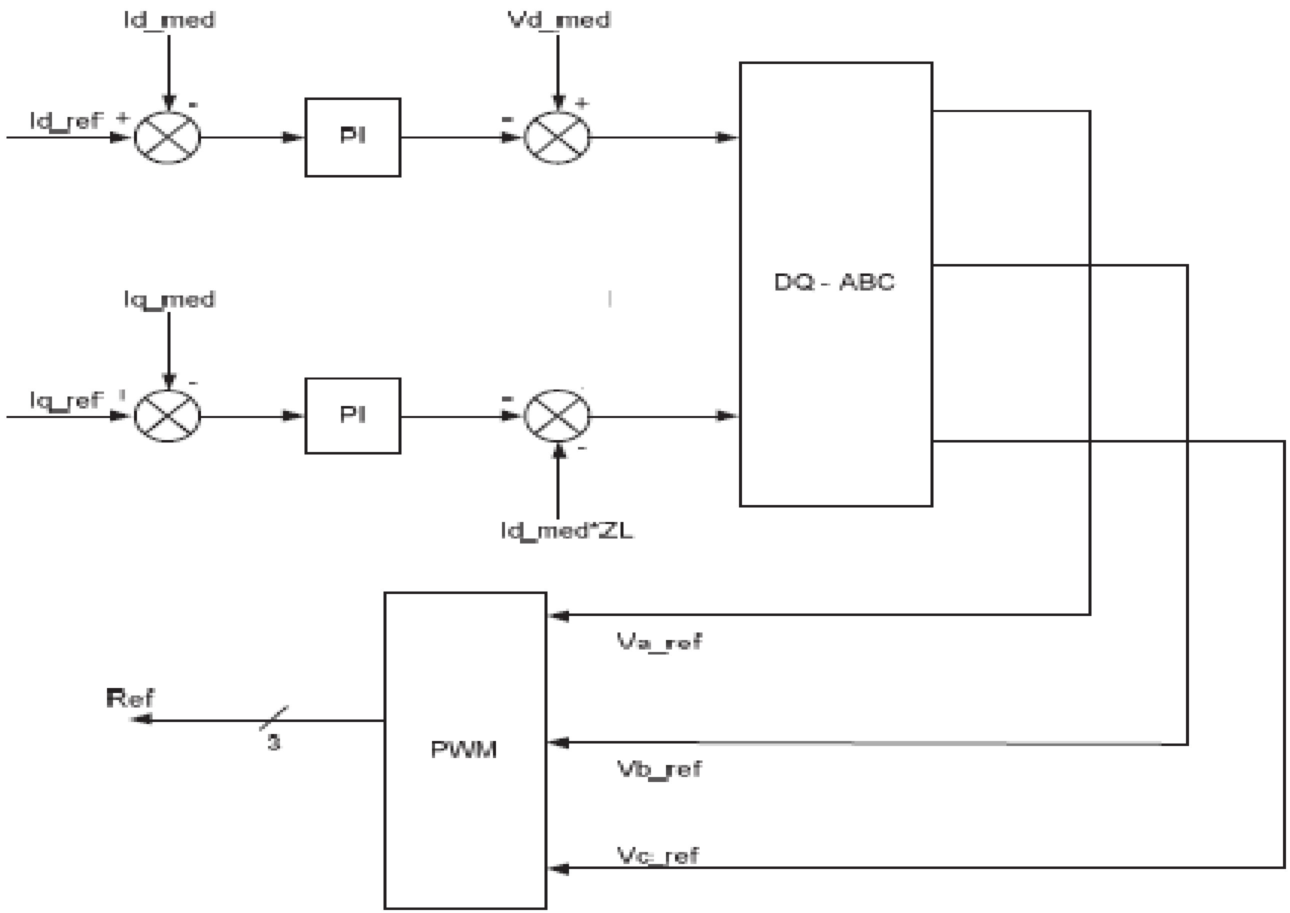
$$\begin{bmatrix}\alpha\\ \beta\end{bmatrix} = \begin{bmatrix}\cos\theta & -\sin\theta\\ \sin\theta & \cos\theta\end{bmatrix}\times\begin{bmatrix}d\\ q\end{bmatrix}$$

$$i_{abc}(t) = T^{-1} i_{\alpha\beta\gamma}(t) = \begin{bmatrix}1 & 0 & 1\\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1\\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1\end{bmatrix}\begin{bmatrix}i_\alpha(t)\\ i_\beta(t)\\ i_\gamma(t)\end{bmatrix}.$$

# 2. Power Converter.

| **Cte.** | **Transf.** | **Inversa** | **Potencia instantánea trifásica** $p(t)$ | $q(t)$ | **Escalado** |
|---|---|---|---|---|---|
| $\sqrt{2/3}$ | T.Clarke | $\boldsymbol{T}^{-1} = \boldsymbol{T}^t$ | $p = v_\alpha i_\alpha + v_\beta i_\beta$ | $q = v_\beta i_\alpha - v_\alpha i_\beta$ | $\sqrt{2/3}$ |
| | T.Park | $\boldsymbol{T}^{-1} = \boldsymbol{T}^t$ | $p = v_d i_d + v_q i_q$ | $q = v_q i_d - v_d i_q$ | $\sqrt{2/3}$ |
| $2/3$ | T.Clarke | $\boldsymbol{T}^{-1} = \frac{3}{2}\boldsymbol{T}^t$ | $p = \frac{3}{2}(v_\alpha i_\alpha + v_\beta i_\beta)$ | $q = \frac{3}{2}(v_\beta i_\alpha - v_\alpha i_\beta)$ | 1 |
| | T.Park | $\boldsymbol{T}^{-1} = \frac{3}{2}\boldsymbol{T}^t$ | $p = \frac{3}{2}(v_d i_d + v_q i_q)$ | $q = \frac{3}{2}(v_q i_d - v_d i_q)$ | 1 |
| 1 | T.Clarke | $\boldsymbol{T}^{-1} = \frac{2}{3}\boldsymbol{T}^t$ | $p = \frac{2}{3}(v_\alpha i_\alpha + v_\beta i_\beta)$ | $q = \frac{2}{3}(v_\beta i_\alpha - v_\alpha i_\beta)$ | 3/2 |
| | T.Park | $\boldsymbol{T}^{-1} = \frac{2}{3}\boldsymbol{T}^t$ | $p = \frac{2}{3}(v_d i_d + v_q i_q)$ | $q = \frac{2}{3}(v_q i_d - v_d i_q)$ | 3/2 |

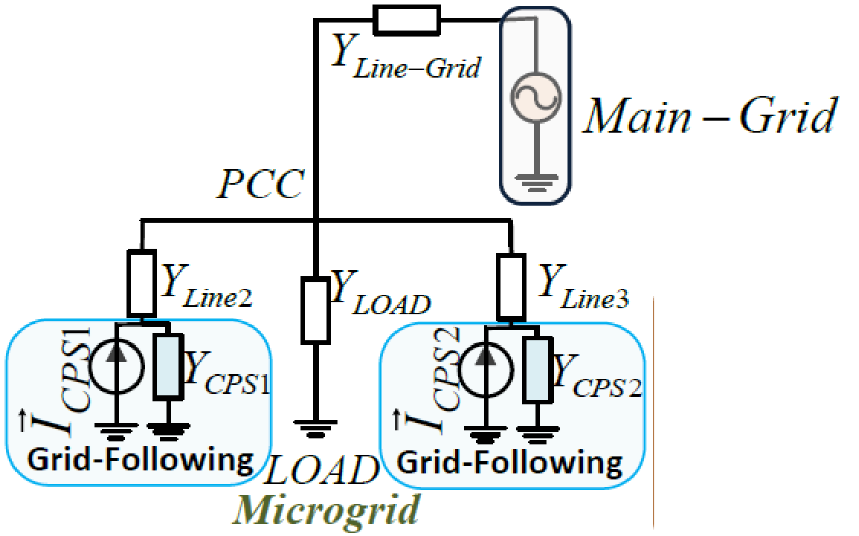
# 2. Power Converter.

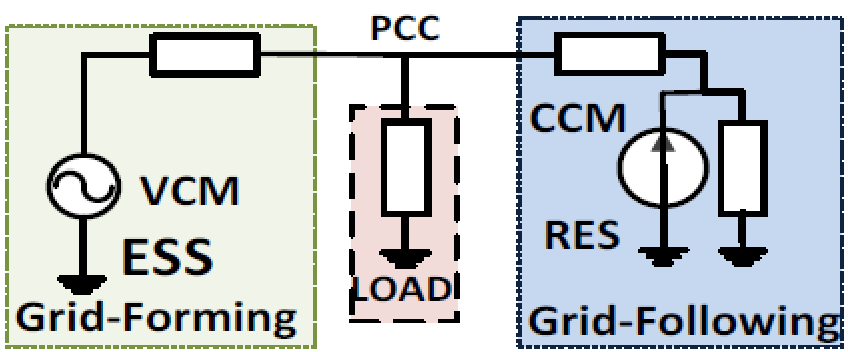



Simulation 10, 11, 12 File.

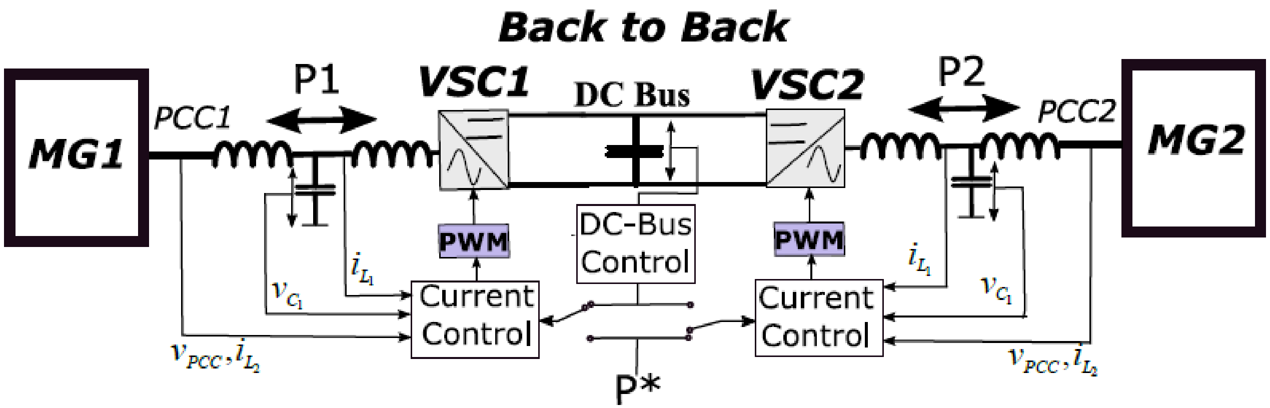
# Interaction of Power Converters

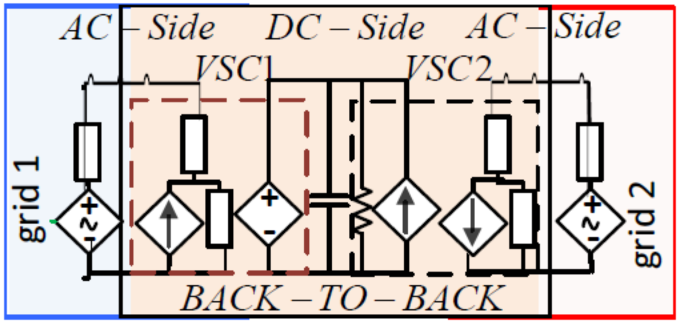
# 2. Power Converter.



# 2. Power Converter.



# 2. Power Converter.