Notes on Matrix Converters

CECA – Convertidors Estàtics de Corrent Altern

Dr. Antoni Arias

Matrix Concept

• AC / AC direct electrical power conversion
• M X N, inputs & outputs. Figure corresponds to the 3 X 3
• Variable frequency and variable voltage

Input RL filter

Bi-directional switch

S \text{Ac}
**Fundamentals**

- Switching function: 
  \[ S_{io}(t) = \begin{cases} 
  1, & \text{open} \\
  0, & \text{closed} 
  \end{cases} \]
  
  \( i = \{ A, B, C \} \)
  
  \( o = \{ a, b, c \} \)

- Transfer Matrix:
  \[
  [T] = \begin{bmatrix}
  S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\
  S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\
  S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t)
  \end{bmatrix}
  \]

- There are \( 2^9 \) (512) possible combinations
- Each output phase can be connected to any input phase
- There are several constraints:
  - Avoid line to line input short circuit
  - Avoid open circuits with inductive currents

\[
S_{Ao}(t) + S_{Bo}(t) + S_{Co}(t) = 1
\]

**Model**

- \[ U_{oN}(t) = \begin{bmatrix}
  U_{aN}(t) \\
  U_{bN}(t) \\
  U_{cN}(t)
  \end{bmatrix} \]

- \[ i_{o}(t) = \begin{bmatrix}
  i_{a}(t) \\
  i_{b}(t) \\
  i_{c}(t)
  \end{bmatrix} \]

- \[ T = \begin{bmatrix}
  S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\
  S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\
  S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t)
  \end{bmatrix} \]

- \[ U_{iN}(t) = [T] \cdot [i_{o}(t)] \]

- \[ i_{i}(t) = [T]^T \cdot [i_{o}(t)] \]

- \[ U_{AN}(t) \]

- \[ U_{BN}(t) \]

- \[ U_{CN}(t) \]
Features

- Direct AC / AC Conversion. No DC Link: all silicon solution
  - Less bulky (compact motor drives)
  - Safer (hostile environments: aircraft, submarine…)
- Bidirectional power flow. 4 quadrant converter
- No restriction on input and output frequency within limits imposed by switching frequency
- Sinusoidal input and output currents waveforms
- 9 bidirectional switches. (18 IGBT + 18 Diodes)
- Output voltage limited to 86.6% ($\cos 30^\circ$) of input voltage

Applications

- Standard:
  - Wind/Water Force Machines (blowers, boilers, incinerators), pumps, and general Industrial Machines.
- Specific Applications:
  - Compact or Integrated Motor Drives
  - Motor Drives for hostile environments (aircrafts, submarines)
  - AC/AC Power Conversions: wind energy, variable speed drives...
- Still a topic of research
Yaskawa Medium voltage FSDrive-MX1S.
- Launched in 2004
- World's first matrix converter Drive
- Super energy-saving medium-voltage Matrix Converter with Power regeneration
- 3kV 200 to 3000kVA
- 6kV 400 to 6000kVA
- Applications:
  - Wind/Water Force Machines (blowers, boilers, incinerators), pumps, and general Industrial Machines.

Yaskawa Low voltage Matrix Converter (Varispeed AC)
- V/f and vector control

Table II: Standard specifications of FSDrive-MX1

<table>
<thead>
<tr>
<th>Output Rating</th>
<th>3.3kV class</th>
<th>6.6kV class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Power Factor</td>
<td>0.95 or more</td>
<td>0.95 or more</td>
</tr>
<tr>
<td>Cooling System</td>
<td>Forced air-cooling by fan</td>
<td>Forced air-cooling by fan</td>
</tr>
<tr>
<td>Speed Control</td>
<td>Sensor-less vector control</td>
<td>Vector control</td>
</tr>
<tr>
<td>Torque Control</td>
<td>Four-quadrant PWM control</td>
<td>-150% to 150%</td>
</tr>
</tbody>
</table>

Table I: Standard specifications of Varispeed AC

<table>
<thead>
<tr>
<th>Output Rating</th>
<th>200V class 9–63kVA</th>
<th>400V class 10–114kVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Power Factor</td>
<td>0.95 or higher</td>
<td>0.95 or higher</td>
</tr>
<tr>
<td>Cooling System</td>
<td>Forced air-cooling by fan</td>
<td>Forced air-cooling by fan</td>
</tr>
<tr>
<td>Speed Control</td>
<td>V/f control</td>
<td>Sensor-less vector control</td>
</tr>
<tr>
<td>Torque Control</td>
<td>Four-quadrant control</td>
<td>-150% to 150%</td>
</tr>
</tbody>
</table>
Waveforms

- $U_{AN}$, $U_{BN}$, $U_{CN}$ input voltages and $U_{aN}$ output voltage
• $U_{AN}$, $U_{BN}$, $U_{CN}$ input voltages and $U_{aN}$ output voltage

• $U_{an} = 2/3 \ U_{aN} - 1/3 \ U_{bN} - 1/3 \ U_{cN} = U_{aN} + U_{Nn}$

• $U_{Nn} = -1/3 \ (U_{aN} + U_{bN} + U_{cN})$
• $U_{an}$ output voltage

$U_{ab} = f (U_{AB}, U_{AC}, U_{BC}, U_{BA}, U_{CA}, U_{CB})$
\[ U_{AB}, U_{AC}, U_{BC}, U_{BA}, U_{CA}, U_{CB} \] input line voltages versus \( U_{ab} \) output line voltage

- It uses the two largest voltages
Waveforms

- **U_{an}** and \( i_a \) inductive current (small dephase or delay)

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Waveforms

Different frequencies $i_{sA}$ $i_a$
Waveforms

- $i_A$: input current and $i_a, i_b, i_c$: load currents
• $i_{SA}$ filtered input current and $i_A$ non filtered input current
Waveforms

- $i_{sA}$ filtered input current and $u_{sA}$ source voltage. Power Factor = 1
Waveforms

- \( U_{SAN} \) source and \( U_{AN} \) input phase voltages
Alternatives

• Industry “workhorse” from less than kW to MW
• Unidirectional power flow
• 2 quadrant
  – When the current changes its sign, the power must be burn in the DC link
• DC link capacitor (30% -50% of the power circuit volume)
• Input currents very poor. (awful THD)

Alternatives

• Bi directional power flow
• 4 quadrant
• DC link capacitor and input inductors
• Sinusoidal input currents. Input Power Factor 1
• Matrix Converter real alternative
MC versus back to back

- 12 IGBTs + 12 Diodes
- 1 large electrolytic capacitor (DC link)
- Input filter (1st order)
  - 3 large inductors
- 18 IGBTs + 18 Diodes
- Input filter (2nd order)
  - 3 inductors
  - 3 capacitors
- Clamp circuit

Bi Directional Switch

- Must be able to conduct positive and negative current and block positive and negative voltage

- Diode embedded switch
  - Switch: 1 IGBT + 4 diodes
  - Conducting losses: 2 diodes +1 IGBT

- Back to back switch with common collector
  - Switch: 2 IGBT + 2 diodes
  - Diode required for reverse blocking capability
  - Conducting losses: 1 diode +1 IGBT

- Back to back switch with common emitter
  - Switch: 2 IGBT + 2 diodes
  - Diode required for reverse blocking capability
  - Conducting losses: 1 diode +1 IGBT
Bi Directional Switch

• Reverse Blocking IGBT, RBIGBT
  – Two reverse blocking IGBTs
  – Lower conducting losses: one switching device
  – Still under research
  – Switch control will remain the same

<table>
<thead>
<tr>
<th>SUMMARY</th>
<th>IGBTs</th>
<th>Diodes</th>
<th>Isolated Power Supplies</th>
<th>Conducting Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode bridge</td>
<td>9</td>
<td>36</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Common Emitter</td>
<td>18</td>
<td>18</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Common Collector</td>
<td>18</td>
<td>18</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

Bi Directional Switch Device Packaging

• Dynex 200 (A) Bi directional Module
  – From standard one leg conventional VSI
  – 9 for a 3x3MC
  – Large Converters > 200 (A)
  – Common collector
Dynex Semiconductor is working closely with researchers at Nottingham University. Through this collaboration and in response to commercial requirements, Dynex has created the DIM400PBM17-A000 for use in a 60Hz to 400Hz fixed frequency converter and the GP200MBS12 for use in a high efficiency brushless dc motor drive. The DIM400PBM17-A000 module is a 400A 1700V bi-directional switch mounted on a 140mm x 73mm metal matrix baseplate. Long-term reliability and enhanced thermal performance are achieved through the use of aluminium nitride substrates mounted on a metal matrix compound baseplate. The package has a 6 kV isolation rating...

The DIM200MBS12-A000 module is a 200A 1200V bi-directional switch mounted on a 106mm x 62mm copper baseplate. The package has a 4 kV isolation rating...


• SEMELAB 200 (A) Bi directional Module
  – 3 for a 3x3MC
  – Large Converters

LOAD

Va Vb Vc
A Matrix Converter IGBT Bi-Directional switching module
A 360kVA (600V max line-line at up to 300A) matrix converter module designed by Semelab.
• IGBT Packaging Available in 300V to 1800V
• Aerospace
• Customised to fit your needs.
• Good CTE match, from Silicon to the metal matrix base plate.
• Excellent reliability module, temp cycling, humidity tested, elevated pressure.
• Low power losses.
• Plastic package / Hermitic packaging
• Power connection,
• Mounting holes
• Void free die attach, X-ray capability.

http://www.semelab.co.uk/power/

Full Matrix Converter Device Packaging

• EUPEC 35A Matrix Converter Module
  – 1 for a 3x3MC
  – Small Powers Converters. 7.5 kW
• Fuji Electric Device Technology Co., Ltd.
  – 1 for a 3x3MC
  – Four options (Price 390 € Nov 2009):
    • 1200V 50A
    • 600V 100A
    • 1200V 100A
    • 600V 200A
Full Matrix Converter Device Packaging

- 600V 200A
- 1200V 100A

Commutation

- Current commutation
  - Needs the sign of the output current per phase
    - Add two anti parallel diodes and measure its voltage drops
    - Measure the device voltage drops
  - Most widely used

- Voltage commutation
  - Needs the input voltage values per phase
4 Step Current Commutation

- No short circuits at the input
- No open circuit at the output (inductive loads)

\[ V_a \to V_B \quad \text{when} \quad I_a > 0 \quad V_a > V_B \]

\[ V_a \to V_B \quad \text{when} \quad I_a < 0 \quad V_a > V_B \]
### Matrix Converter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUPEC FM35R12KE3ENG module</td>
<td></td>
</tr>
<tr>
<td>Switching device</td>
<td>1200V, 35 A, IGBT</td>
</tr>
<tr>
<td>$t_{d1} / t_c / t_{d2}$</td>
<td>1 / 0.2 / 0.5 μs</td>
</tr>
<tr>
<td>$t_f / t_r$</td>
<td>65-90 ns / 30-45 ns</td>
</tr>
<tr>
<td>Power</td>
<td>7.5 kW</td>
</tr>
<tr>
<td>AC Input voltage</td>
<td>3 x 415V</td>
</tr>
<tr>
<td>Input filter (L/C) values</td>
<td>1mH / 1.5μF</td>
</tr>
</tbody>
</table>

### Input Filter

- 2nd Order Input L-C filter
  - Typical cut off frequency 1-3 kHz
    - between the fundamental 50Hz
    - and the PWM frequency 10-20 kHz
  - R in parallel with L in order to have an adequate damping
  - L impedance at 50Hz should be negligible
    - $2\pi f^2 L = 2 \times 3.14 \times 50 \times 10^{-3} = 0.314 \text{ ohms}$

Matrix Converter

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Clamp circuit

- Diode bridge like a standard rectifier
- Protection against
  - open circuits with inductive currents
  - over voltage caused by transients in power up and voltage sags

\[
U_{\text{a}} = U_{\text{A}} \cos (30^\circ), \quad U_{\text{b}} = U_{\text{B}} \cos (-90^\circ), \quad U_{\text{c}} = U_{\text{B}} \cos (-90^\circ)
\]

\[
\bar{U}_o(t) = \frac{2}{3} \left( U_{\text{a}}(t) + U_{\text{b}}(t) e^{j3\pi/2} + U_{\text{c}}(t) e^{j5\pi/6} \right)
\]

MC Output Voltage vectors

- Space Vector Concept:

<table>
<thead>
<tr>
<th>State +1</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U_{\text{a}} = U_{\text{A}} )</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
U_{\text{a}} &= \hat{U}_A \cos (30^\circ) \\
U_{\text{b}} &= \hat{U}_B \cos (-90^\circ) \\
U_{\text{c}} &= \hat{U}_B \cos (-90^\circ)
\end{align*}
\]

\[
\begin{align*}
\hat{U}_A &= 0.86 \hat{U}_A \\
\hat{U}_B &= \frac{2}{3} U_{\text{AB}} |0^\circ|
\end{align*}
\]

\[
\begin{align*}
\hat{U}_A &= \hat{U}_B \\
\hat{U}_B &= \frac{2}{3} U_{\text{AB}} |0^\circ|
\end{align*}
\]

\[
\begin{align*}
\hat{U}_A &= 0.86 \hat{U}_B \\
\hat{U}_B &= 0.86 \hat{U}_B \\
\hat{U}_B &= 0.86 \hat{U}_B \\
\hat{U}_B &= 0.86 \hat{U}_B
\end{align*}
\]

\[
2/3 U_{\text{AB}} |0^\circ|
\]
MC Output Voltage vectors

- Variable amplitude
- Same angle

MC Input Current vectors

- Space Vector Concept:

\[ \bar{i}(t) = \frac{2}{3} \left( i_A(t) + i_B(t) \cdot e^{j\frac{2\pi}{3}} + i_C(t) \cdot e^{j\frac{4\pi}{3}} \right) \]

State +1

\[ i_A = i_a \quad i_B = i_b + i_c \quad i_C = 0 \]

- Amplitude dependant on the load
- Same angle
27 vectors: 18 constant in direction + 3 nulls + 6 rotating
Modulation

- PWM Modulation technique is applied in order to:
  - follow a reference at the output, which on average will be a sinusoidal
  - get sinusoidal input currents on phase with the input voltage (power factor 1)
- Several modulation techniques:
  - Venturini, Scalar...
- Direct & Indirect Space Vector Modulation
  - Based on the Space Vector Modulation for Standard PWM Inverters
  - There are two references:
    - Output voltage vector
    - Input current angle

### Direct Space Vector Modulation

- Output voltage vector: \( \vec{V}_0 \)
- The voltage reference vector will be synthesized using adjacent vectors:
  \[ V_0 = V_0' + V_0'' \]
Direct Space Vector Modulation

Reference 2

- Input current angle: $\tilde{\beta}_0$

  where usually: $\varphi_i = 0$

- The input current angle will be obtained distributing the load current among adjacent vectors in the right proportions:

$$\dot{i}_i = \dot{i}_i' + \dot{i}_i''$$

Reference 1, output voltage vector:

$$v_0 = v_0' + v_0''$$

$$y = v_0' \cdot \cos \frac{\pi}{6} = v_0 \cdot \cos \left( \frac{\pi}{6} + \frac{\pi}{6} - \tilde{\alpha}_0 \right)$$

$$v_0' = \frac{\sqrt{3}}{2} = v_0 \cdot \cos \left( \frac{\pi}{3} - \tilde{\alpha}_0 \right)$$

$$v_0' = \frac{2}{\sqrt{3}} v_0 \cdot \cos \left( \frac{\pi}{3} - \tilde{\alpha}_0 \right) = \frac{2}{\sqrt{3}} v_0 \cdot \cos \left( \tilde{\alpha}_0 - \frac{\pi}{3} \right)$$

$$v_0' = \frac{2}{\sqrt{3}} v_0 \cdot \cos \left( \tilde{\alpha}_0 - \frac{\pi}{3} \right) \cdot e^{j \left[ (K_v - 1) \frac{\pi}{3} + \frac{\pi}{3} \right]}$$

$$-\frac{\pi}{6} \leq \tilde{\alpha}_0 \leq \frac{\pi}{6}$$

$$\alpha_0 = \tilde{\alpha}_0 + \frac{\pi}{6}$$
• What vectors can be used?
  – Maximum input voltages at \( K_i=1 \): \( U_{AB}, U_{AC} \).
  – Common vectors For \( K_v=1 & K_i=1 \):
    \[ \pm 1 \quad \pm 2/3 \quad \pm 3 \quad \pm 2/3 \quad \pm 3 \]
  – Using just 2 vectors, both references cannot be fulfilled \( \rightarrow \) 4 active vectors will be used.
Direct Space Vector Modulation

\[ \vec{v}_0' = \frac{2}{\sqrt{3}} v_0 \cdot \cos\left(\tilde{\alpha}_0 - \frac{\pi}{3}\right) \cdot e^{j \left[ (K_v - 1) \frac{\pi}{3} + \frac{\pi}{3} \right]} = v_o \cdot \delta^I + v_o \cdot \delta^II \]

\[ \vec{v}_0'' = \frac{2}{\sqrt{3}} v_0 \cdot \cos\left(\tilde{\alpha}_0 + \frac{\pi}{3}\right) \cdot e^{j \left[ (K_v - 1) \frac{\pi}{3} \right]} = v_o \cdot \delta^III + v_o \cdot \delta^IV \]

Direct Space Vector Modulation

Reference 2, input current angle

\[ \dot{i}_i = \dot{i}_i^I + \dot{i}_i^II \]

\[ \dot{i}_i = \dot{i}_i^I \cdot \delta^I + \dot{i}_i^III \cdot \delta^III + \dot{i}_i^IV \cdot \delta^IV \]

\[ \left( \dot{i}_i^I \cdot \delta^I + \dot{i}_i^II \cdot \delta^II \right) \cdot j e^{j \tilde{\beta}_i} \cdot e^{j (K_v - 1) \frac{\pi}{3}} = 0 \]

\[ \left( \dot{i}_i^III \cdot \delta^III + \dot{i}_i^IV \cdot \delta^IV \right) \cdot j e^{j \tilde{\beta}_i} \cdot e^{j (K_v - 1) \frac{\pi}{3}} = 0 \]
Direct Space Vector Modulation

\[ \vec{v}_0 = \frac{2}{\sqrt{3}} v_0 \cos \left( \alpha_0 - \frac{\pi}{3} \right) \cdot e^{j(\kappa_1 - \frac{\pi}{3})} = v_0 \cdot \delta^I + v_o \cdot \delta^II \]

\[ \vec{v}_0 = \frac{2}{\sqrt{3}} v_0 \cos \left( \alpha_0 + \frac{\pi}{3} \right) \cdot e^{j(\kappa_2 - \frac{\pi}{3})} = v_o \cdot \delta^III + v_o \cdot \delta^IV \]

\[ \left( i \cdot \delta^I + I \cdot \delta^II \right) \cdot j e^{j(\kappa_1 - \frac{\pi}{3})} = 0 \]

\[ \left( i \cdot \delta^III + I \cdot \delta^IV \right) \cdot j e^{j(\kappa_1 - \frac{\pi}{3})} = 0 \]

- Solving the 4 equations, the four duty cycles are found
- The remaining duty is for the zero vectors

\[ \delta^0 = 1 - \left( \delta^I + \delta^II + \delta^III + \delta^IV \right) \]

Indirect Space Vector Modulation

Rectification stage

Inversion stage

- To obtain a correct balance of the input currents and the output voltages, the modulation pattern should be a combination of all 4 duty-cycles

\[ d_y = m_y \cdot \sin \left( \frac{\pi}{3} - \theta^{'in} \right) \]

\[ d_\delta = m_\delta \cdot \sin (\theta^{'in}) \]

\[ d_a = m_a \cdot \sin \left( \frac{\pi}{3} - \theta^{'out} \right) \]

\[ d_\beta = m_\beta \cdot \sin (\theta^{'out}) \]

- And the zero vector is calculated as follows

\[ d_0 = 1 - (d_y + d_\delta + d_\beta + d_\gamma) \]

- The typical modulation pattern is as shown in next slide
Modulation switching pattern

Input sector 1. Input angle 0° Output sector 1. Output angle 30°

<table>
<thead>
<tr>
<th>Input sector</th>
<th>Output sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u_c \rightarrow u_a$</td>
<td>$u_a \rightarrow u_a$</td>
</tr>
<tr>
<td>$u_a \rightarrow u_b$</td>
<td>$u_b \rightarrow u_a$</td>
</tr>
<tr>
<td>$u_b \rightarrow u_c$</td>
<td>$u_c \rightarrow u_c$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sector</th>
<th>$U_c$</th>
<th>$U_a$</th>
<th>$U_b$</th>
<th>$U_c$</th>
<th>$U_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-3</td>
<td>-7</td>
<td>+1</td>
<td>+1</td>
<td>-7</td>
</tr>
<tr>
<td>0.5</td>
<td>$\delta_{3/2}$</td>
<td>$\delta_{3/2}$</td>
<td>$\delta_{1/2}$</td>
<td>$\delta_{1/2}$</td>
<td>$\delta_{3/2}$</td>
</tr>
<tr>
<td>0.5</td>
<td>$\delta_{3/2}$</td>
<td>$\delta_{1/2}$</td>
<td>$\delta_{3/2}$</td>
<td>$\delta_{3/2}$</td>
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<tr>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>-1</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

$V_{bN}$ $V_{bN}$ $V_{cN}$ $V_{dN}$ $V_{dN}$ $V_{an}$ $V_{bn}$ $V_{cn}$
Modulation switching pattern

Input sector 1. Input angle +30º  Output sector 1. Output angle +30º

<table>
<thead>
<tr>
<th>$U_C$</th>
<th>$U_A$</th>
<th>$U_B$</th>
<th>$U_A$</th>
<th>$U_B$</th>
<th>$U_A$</th>
<th>$U_B$</th>
<th>$U_A$</th>
<th>$U_B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>-7</td>
<td>+1</td>
<td>+1</td>
<td>-7</td>
<td>+1</td>
<td>-7</td>
<td>+1</td>
<td>-7</td>
</tr>
<tr>
<td>$\frac{\delta_{03}}{2}$</td>
<td>$\frac{\delta_{1}}{2}$</td>
<td>$\frac{\delta_{01}}{2}$</td>
<td>$\frac{\delta_{03}}{2}$</td>
<td>$\frac{\delta_{1}}{2}$</td>
<td>$\frac{\delta_{01}}{2}$</td>
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<td>$\frac{\delta_{1}}{2}$</td>
<td>$\frac{\delta_{01}}{2}$</td>
</tr>
</tbody>
</table>

- $U_{an}$
- $U_{bn}$
- $U_{cn}$
- $U_{NN}$
- $U_{an}$
- $U_{bn}$
- $U_{cn}$

Input sector 1. Input angle +30º

Output sector 1. Output angle +30º

Modulation switching pattern
Matrix Converter linearization

- General scheme

- Voltage Drop effect

- Four step commutation
  - \((t_{d1} + t_c + t_{d2} = 1\mu s + 0.2\mu s + 0.5\mu s)\)

- Voltage Edge Uncertainty effect
Matrix Converter linearization

- Model for Voltage Edge Uncertainty effect
- SVM

Matrix Converter linearization

SECTOR 1

\[
\begin{array}{c|c|c|c|c|c|c|c|c}
V_C & V_A & V_B & V_A & V_B & V_A & V_B \\
\frac{\delta_0}{2} & \frac{\delta_1}{2} & \frac{\delta_0}{2} & \frac{\delta_1}{2} & \frac{\delta_0}{2} & \frac{\delta_1}{2} & \frac{\delta_0}{2} & \frac{\delta_1}{2} \\
V_c \text{ ideal} & V_a \text{ ideal} & V_b \text{ ideal} & V_a \text{ ideal} & V_b \text{ ideal} & V_a \text{ ideal} & V_b \text{ ideal} \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
T_{PWM} & T_{PWM} & T_{PWM} & T_{PWM} & T_{PWM} & T_{PWM} & T_{PWM} \\
\end{array}
\]

DUAL COMPENSATION

- Voltage Drop effect
- Voltage Edge Uncertainty effect
- Dual Compensation
Matrix Converter linearization

Summary

- Matrix Converter topology
  - 9 Bidirectional switch
- 4 step commutation
- Space Vector Modulation
- Input Filter
- Clamp Circuit
- Matrix Converter linearization
- Advantages of Matrix Converters:
  - Size. Compactness.
  - Sinusoidal input/output
  - Hostile environments
  - 4 quadrant

- Applications