AT-NPC Module Switching Pattern (M404 Single Phase)

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What is the “three level”? 

(1) $V_{out} = +E$

(2) $V_{out} = 0$

(3) $V_{out} = -E$

Three level outputs! ($+E$, $0$, $-E$)
NPC & T-type 3-level Configuration

(1) $V_{out} = +E$

(3) $V_{out} = -E$

$V_{out}$
Switching Pattern

(2)

\[ V_{\text{out}} = 0 \]
Generate PWM Pulse

Carrier wave 1

Reference wave

Carrier wave 2

T1

T3

T4

T2
Switching Pattern (Phase Voltage)

Carrier wave 1
Reference wave
Carrier wave 2

T1
T3
T4
T2
Switching Pattern (Phase Voltage)

Output voltage (Phase voltage)

After filtering

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Phase Voltage Output Pattern
(No current delay)
Switching Pattern (Phase Voltage)

\[ V_{\text{out}} = 0 \]

\[ +E \]

\[ -E \]
Switching Pattern (Phase Voltage)

$V_{out} = +E$

$V_{out} = -E$

T1 OFF

T2 ON

T3 OFF

T4 OFF

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Switching Pattern (Phase Voltage)

Switching Pattern Diagram:

- **T1**
- **T3**
- **T4**
- **T2**

**Vout**

Switching States:

- **T1** and **T4** OFF, **T2** and **T3** ON:
  - $V_{out} = 0$

Diagram showing the phase voltage and switching states for different transistors.
Switching Pattern (Phase Voltage)

Switching Pattern:

- **T1**
  - OFF
  - ON

- **T3**
  - OFF
  - ON

- **T4**
  - OFF
  - ON

- **T2**
  - OFF
  - ON

- **V_{out}**
  - OFF
  - ON

Diagram:

- **E**
  - T2 ON
  - T3 OFF
  - T4 OFF

- **V_{out} = +E**
Switching Pattern (Phase Voltage)

T1
T3
T4
T2

$V_{out} = 0$
Switching Pattern (Phase Voltage)

T1
T3
T4
T2

$V_{out}$

$V_{out} = +E$

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Switching Pattern (Phase Voltage)

Switching pattern diagram showing the switching states of transistors T1, T2, T3, and T4. The graph illustrates the phase voltage and the corresponding output voltage for each transistor state. The output voltage $V_{out}$ is depicted as a series of bars, indicating the voltage levels and their timing relative to the phase voltage waveform.

Diagram shows:
- T1: ON when $V_{out}$ is high, OFF when $V_{out}$ is low.
- T2: OFF when $V_{out}$ is high, ON when $V_{out}$ is low.
- T3: ON when $V_{out}$ is low, OFF when $V_{out}$ is high.
- T4: OFF when $V_{out}$ is low, ON when $V_{out}$ is high.

The diagram illustrates the idealized switching pattern where $V_{out} = 0$ when the opposite transistors are active.

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Switching Pattern (Phase Voltage)

\[ V_{\text{out}} = +E \]
Switching Pattern (Phase Voltage)

V_{\text{out}} = 0

T1 \quad \text{ON}

T2 \quad \text{ON}

T3 \quad \text{OFF}

T4 \quad \text{OFF}

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Switching Pattern (Phase Voltage)

Diagram showing the switching pattern for phases T1, T3, T4, and T2, with corresponding voltage output $V_{out}$. The diagram illustrates the on and off states of the transistors T1, T2, T3, and T4, with $V_{out} = +E$. The waveform graphically represents the voltage output over time.
Switching Pattern (Phase Voltage)

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Switching Pattern (Phase Voltage)

T1
T2
T3
T4

V_{\text{out}}

E

T2 \quad \text{OFF}

T3 \quad \text{ON}

V_{\text{out}} = -E

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Switching Pattern (Phase Voltage)

Switching Pattern Diagram:

- **T1**: ON
- **T3**: OFF
- **T4**: ON
- **T2**: OFF

Output Voltage ($V_{out}$):

$V_{out} = 0$
Switching Pattern (Phase Voltage)

Switching Process:

- **T1**: On
- **T3**: Off
- **T4**: On
- **T2**: Off

Voltage Output:

\[ V_{out} = -E \]
Switching Pattern (Phase Voltage)

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V_{out} = 0

T1 OFF

T3 ON

T4 OFF

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Switching Pattern (Phase Voltage)

Switching Pattern:
- T1
- T3
- T4
- T2

Graph showing the switching pattern of the phase voltage.

Circuit Diagram:
- T1: OFF
- T2: OFF
- V_{out} = -E
- T3: ON
- T4: ON

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Switching Pattern (Phase Voltage)

Switching Pattern:
- T1 and T2 are OFF.
- T3 and T4 are ON.

Output Voltage: $V_{out} = 0$

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Switching Pattern (Phase Voltage)

\[ V_{\text{out}} = -E \]
Switching Pattern (Phase Voltage)

$V_{out} = 0$

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Switching Pattern (Phase Voltage)

\[ V_{\text{out}} = -E \]
Switching Pattern (Phase Voltage)

- **T1**, **T3**, **T4**, **T2**

- **$V_{out}$**

- Diagram showing switching patterns and phase voltage

- **$V_{out} = 0$**
Inductive load - Delayed current
Inductive Load – Lagging Current

If an inductive load is connected, the current waveform is lagging behind the voltage waveform.

Current delay: $\alpha$
Power factor: $\cos \alpha$
Switching Mode

(1) SW mode B
   T1: Free wheeling
   T3: Switching

(2) SW mode A
   T1: Switching
   Tc: Free wheeling

(3) SW mode B'
   T4: Free wheeling

(4) SW mode A'
   T2: Switching
   T3: Free wheeling
Switching Pattern (1) SW mode B

T1: OFF
T2: ON
T3: Turn on (Free wheeling)
T4: OFF
Switching Pattern (1) SW mode B

- **T1**: Free wheeling
- **T2**: ON
- **T3**: Turn off
- **T4**: OFF

**Circuit Diagram**:
- T1: ON
- T2: ON
- T3: OFF
- T4: OFF

**Waveforms**:
- **$V_{out}$**
- **$I_{out}$**
Switching Pattern (1) SW mode B

T1: Reverse recovery
T2: ON
T3: Turn on (Free wheeling)
T4: OFF
Switching Pattern (1) SW mode B

T1: Free wheeling
T2: ON
T3: Turn off
T4: OFF
Switching Pattern (2) SW mode A

- **T1**: Turn on (No switching loss)
- **T3**: OFF
- **T4**: OFF

Diagram showing the states of T1, T2, T3, and T4, with waveforms for $V_{out}$ and $I_{out}$.
Switching Pattern (2) SW mode A

- **T1**: Turn off
- **T2**: Free wheeling
- **T3**: ON
- **T4**: OFF

**Diagram:**

- **V_{out}** and **I_{out}** waveforms are shown.
- The diagram illustrates the switching patterns for each transistor state.

**Legend:**

- **T1: ON**, **T3: ON**, **T4: OFF**
- **T2: OFF**
Switching Pattern (2) SW mode A

T1: Turn on
T2: Reverse recovery
T3: OFF
T4: OFF

T1
T3
T4
T2

V_{out}
I_{out}

I_{out}

T2 ON
T4 OFF
T3 OFF
Switching Pattern (2) SW mode A

T1: Turn off
T2: Free wheeling
T3: ON
T4: OFF

V_{out} \quad I_{out}
Switching Pattern (2) SW mode A

T1: Turn on
T2: Reverse recovery
T3: OFF
T4: OFF

T1
T3
T4
T2

V_{out}
I_{out}

T2 \text{ ON}
T3 \text{ OFF}
T4 \text{ OFF}

T1 \text{ ON}
I_{out}
Switching Pattern (2) SW mode A

- **T1:** Turn off
- **T2:** Free wheeling
- **T3:** ON
- **T4:** OFF

Diagram showing the switching pattern with time waveforms for $V_{out}$ and $I_{out}$, and a circuit diagram illustrating the state of each transistor (T1, T2, T3, T4) and the direction of the current $I_{out}$. The diagram also highlights the operation modes for each transistor.
Switching Pattern (2) SW mode A

T1: Turn on
T2: Reverse recovery
T3: OFF
T4: OFF

T1
T3
T4
T2

V_{out}
I_{out}
Switching Pattern (2) SW mode A

T1: Turn off
T2: Free wheeling
T3: ON
T4: OFF
Switching Pattern (3) SW mode B’

T1: OFF
T2: Free wheeling
T3: ON
T4: OFF
Switching Pattern (3) SW mode B’

T1: OFF
T2: Turn off
T3: ON
T4: Free wheeling
Switching Pattern (3) SW mode B’

- **T1**: OFF
- **T2**: Turn on (Free Wheeling)
- **T3**: ON
- **T4**: Reverse recovery
Switching Pattern (3) SW mode B’

- T1: OFF
- T2: Turn off
- T3: ON
- T4: Free wheeling

**Diagram:**
- T1: Red
- T3: Red
- T4: Light blue
- T2: Blue

**Graphs:**
- $V_{out}$
- $I_{out}$

**Circuit Diagram:**
- T1 OFF
- T2 OFF
- T3 ON
- T4 ON

- $I_{out}$

**Additional Information:**
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Switching Pattern (4) SW mode A’

T1: OFF
T2: OFF
T3: ON
T4: Turn on (No switching loss)
Switching Pattern (4) SW mode A’

- **T1**: OFF
- **T2**: ON
- **T3**: Free wheeling
- **T4**: Turn off
Switching Pattern (4) SW mode A’

T1: OFF
T2: OFF
T3: Reverse recovery
T4: Turn on
Switching Pattern (4) SW mode A’

T1: OFF
T2: ON
T3: Free wheeling
T4: Turn off

V_{out}
I_{out}
Switching Pattern (4) SW mode A’

T1: OFF
T2: OFF
T3: Reverse recovery
T4: Turn on
Switching Pattern (4) SW mode A’

T1: OFF
T2: ON
T3: Free wheeling
T4: Turn off
Switching Pattern (4) SW mode A’

T1: OFF
T2: OFF
T3: Reverse recovery
T4: Turn on
Switching Pattern (4) SW mode A’

T1: OFF
T2: ON
T3: Free wheeling
T4: Turn off

V_{out}, I_{out}