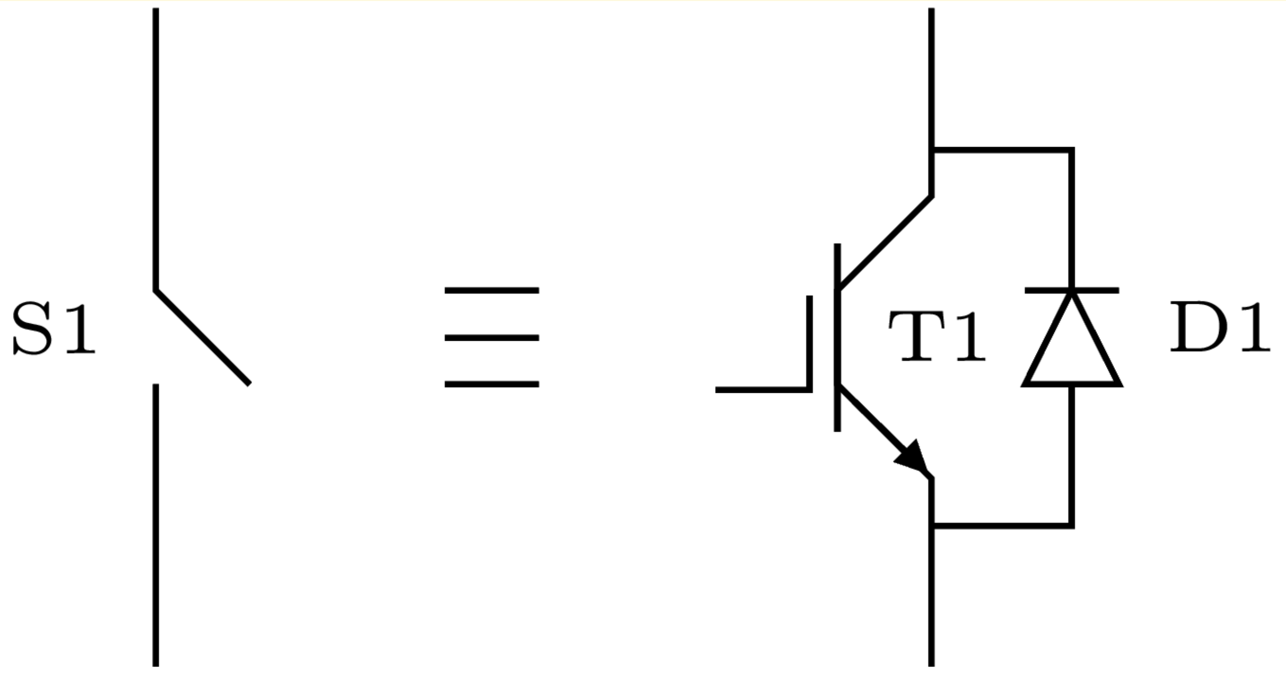
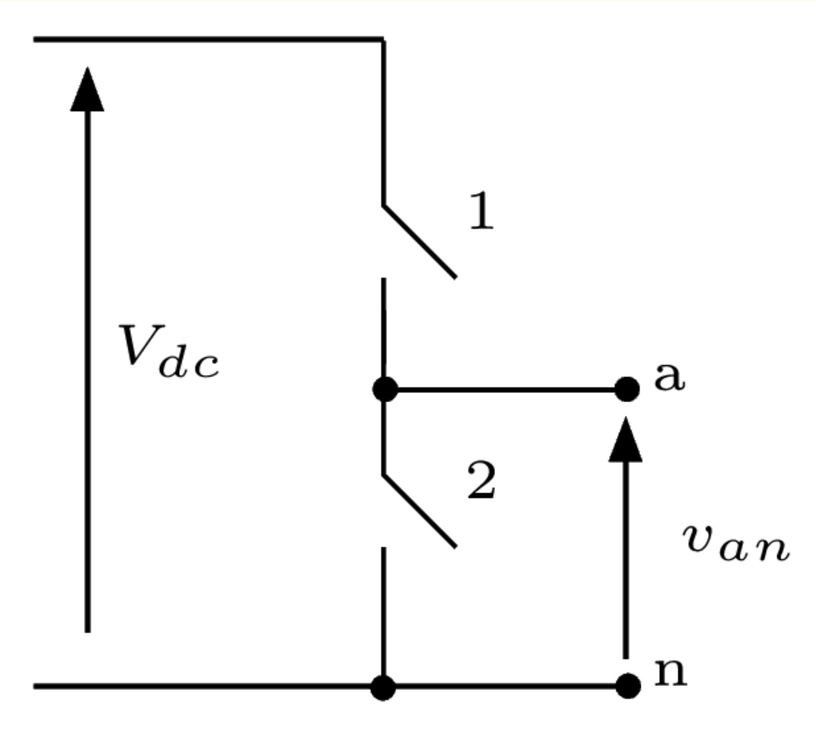
Voltage source converters (VSCs)

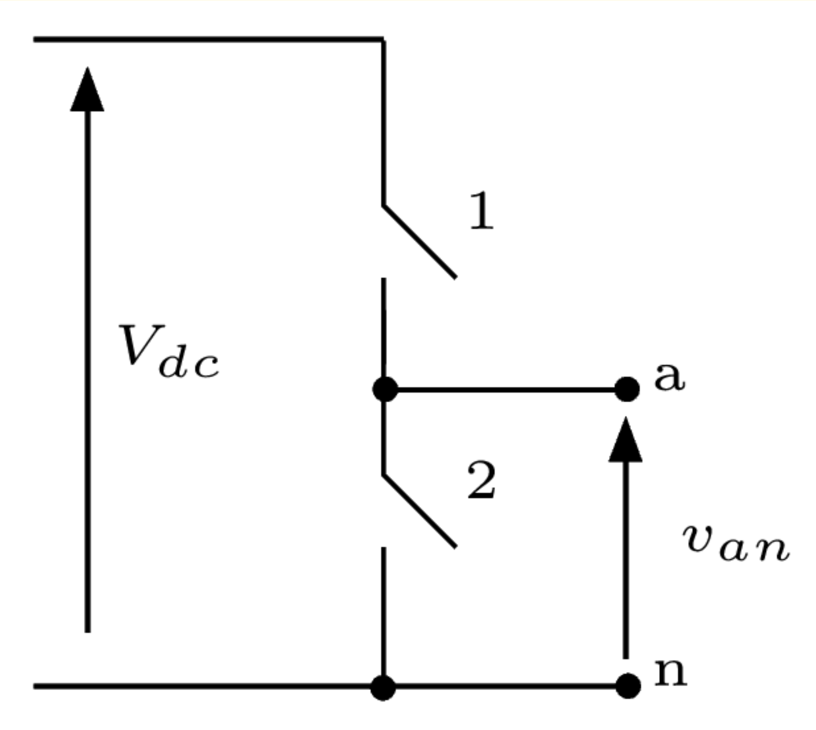
Switch used:



Half bridge VSC



Half bridge VSC

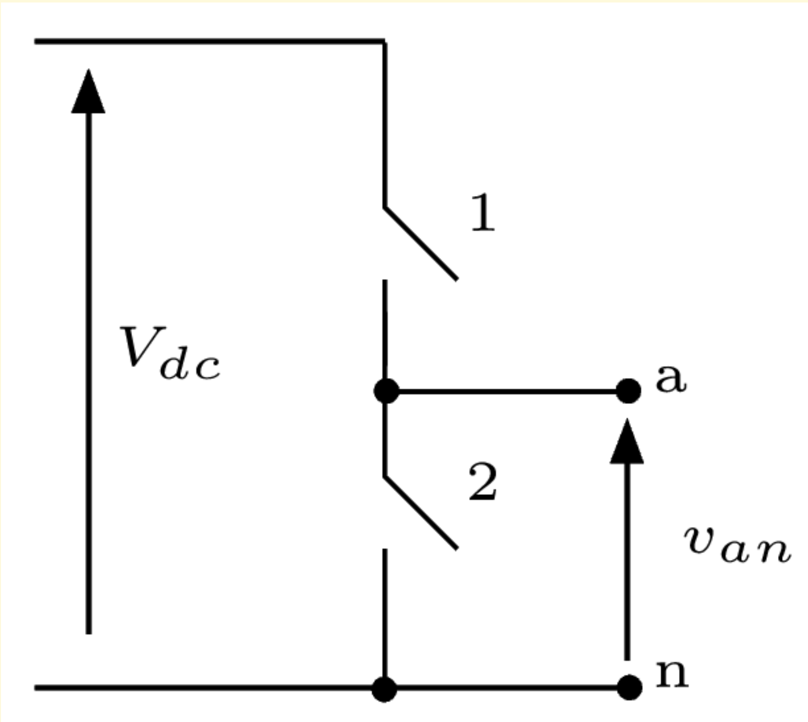


Switches S1 and S2 are complementary to each other

$$v_{an} = V_{dc} \quad \text{... if S1 is ON}$$

$$= 0 \quad \text{... if S2 is ON}$$

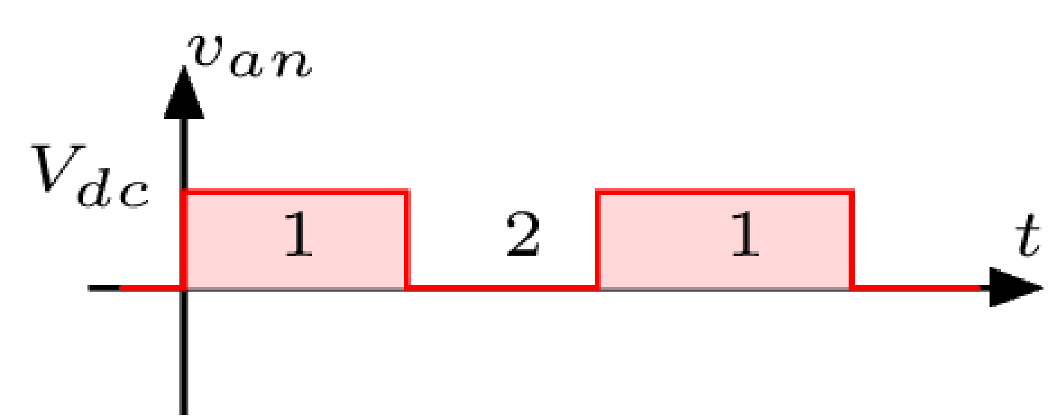
Half bridge VSC



Switches S1 and S2 are complementary to each other

v_{an} = V_{dc} ... if S1 is ON

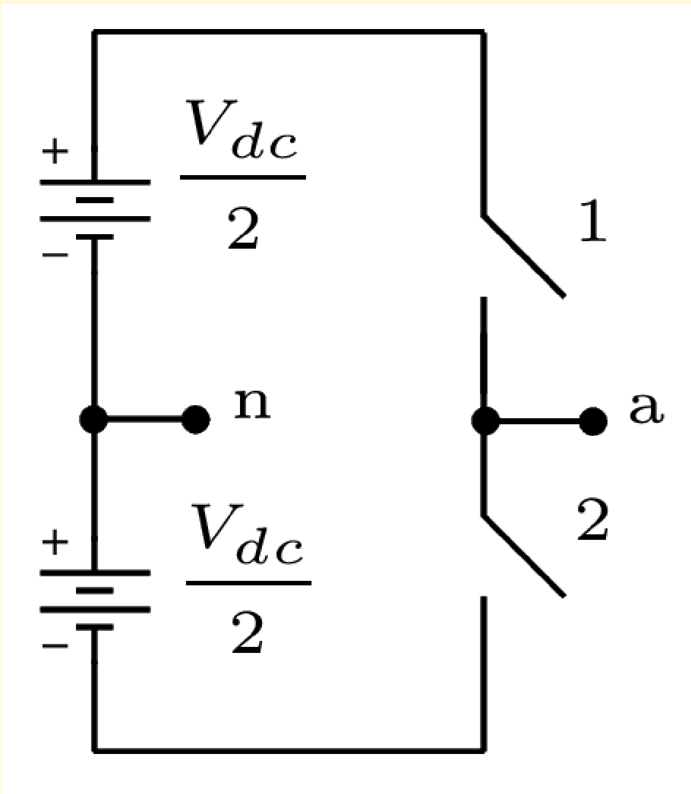
= 0 ... if S2 is ON



Assuming $\mathbf{V_{dc}}$ is constant

Half bridge VSC

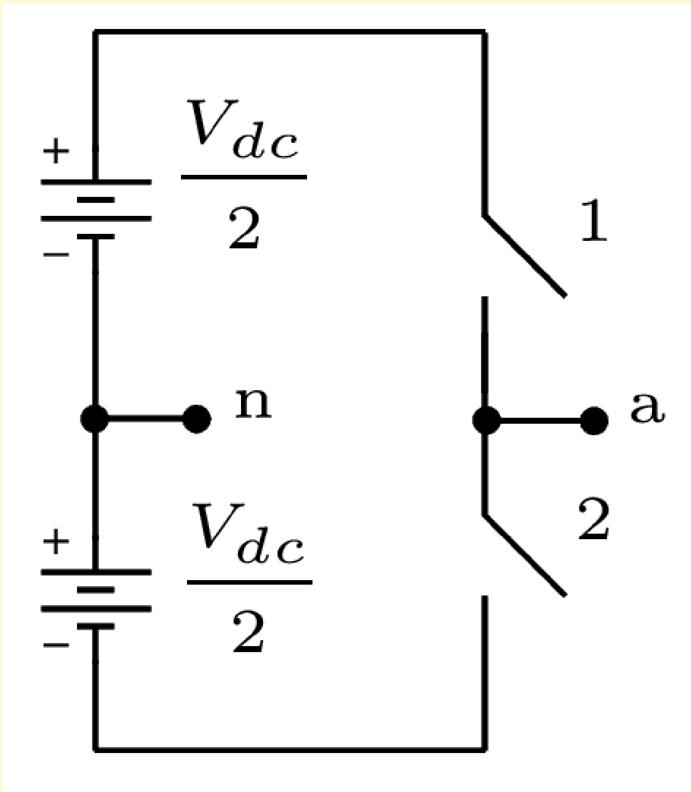
Consider:

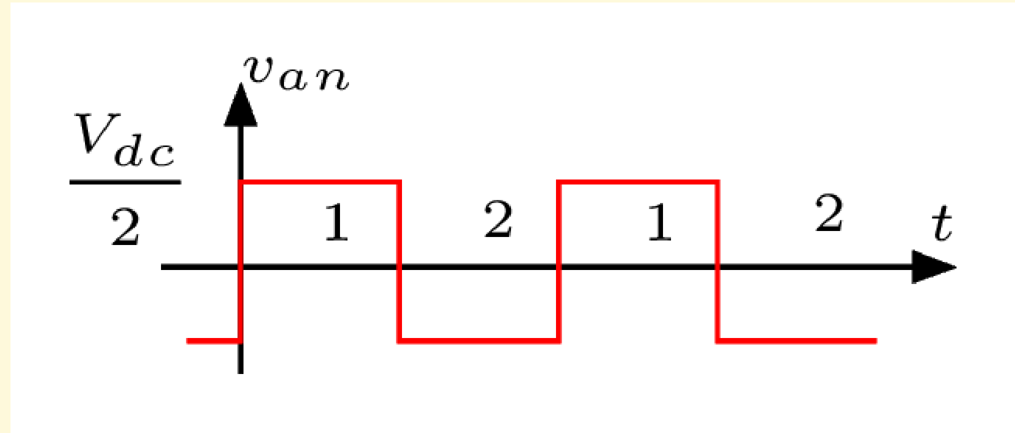


Assuming $\mathbf{V_{dc}}$ is constant

Half bridge VSC

Consider:



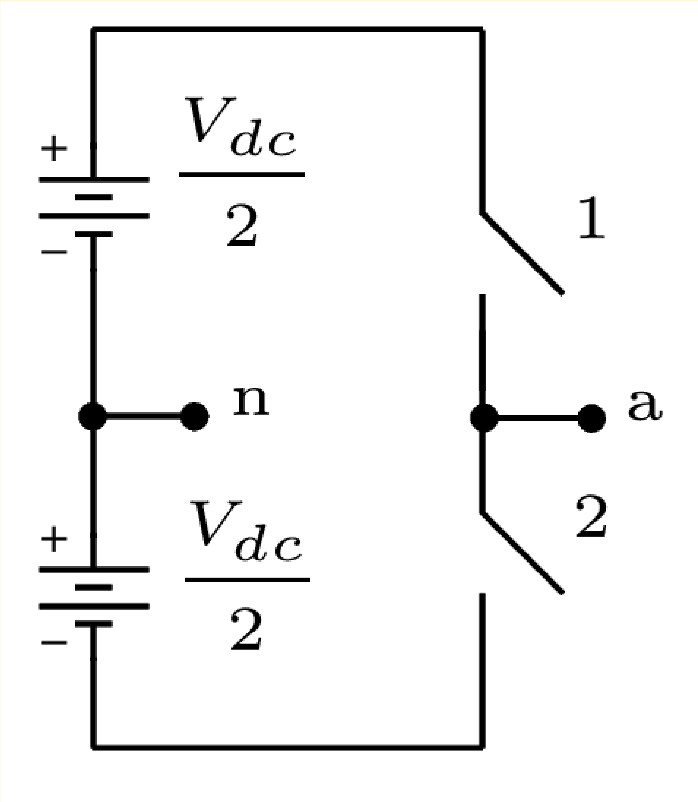


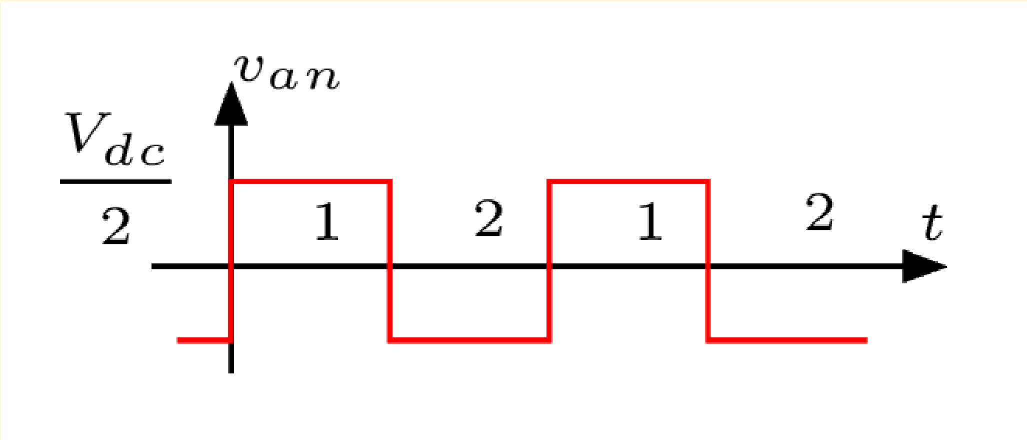
Fundamental + harmonic components

Assuming $\mathbf{V_{dc}}$ is constant

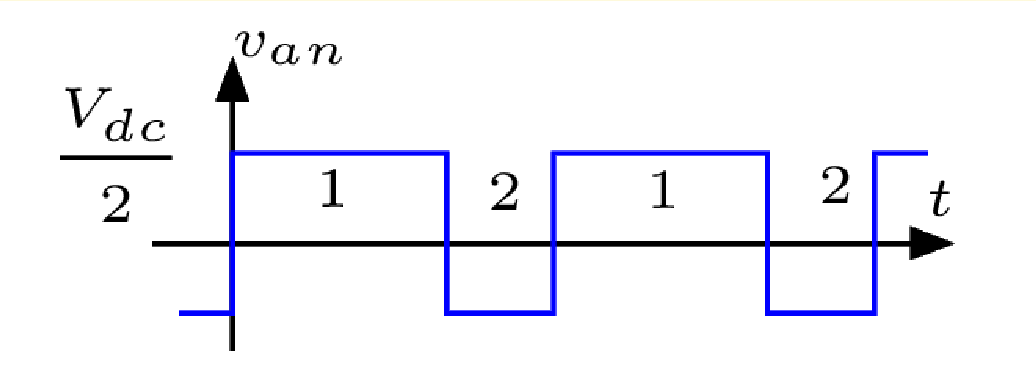
Half bridge VSC

Consider:





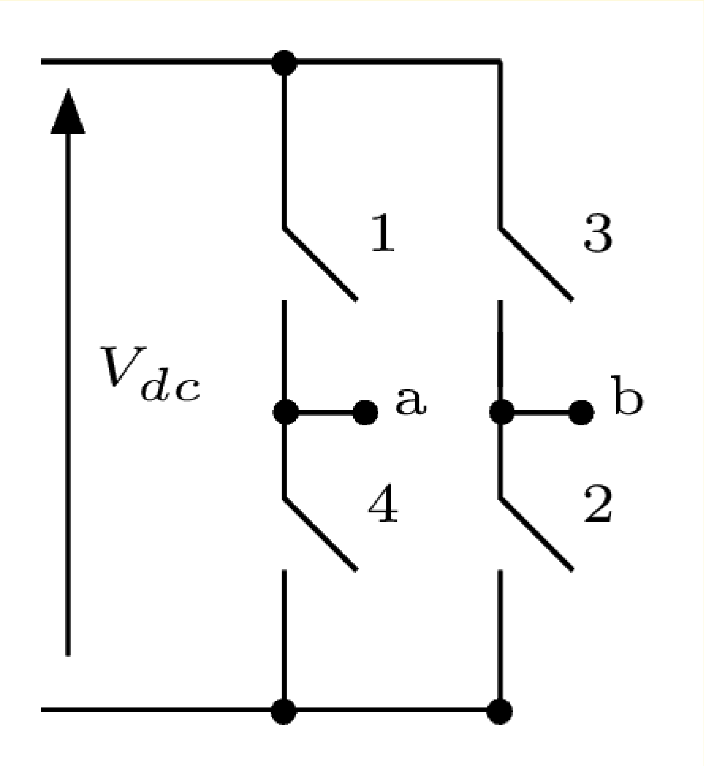
Fundamental + harmonic components



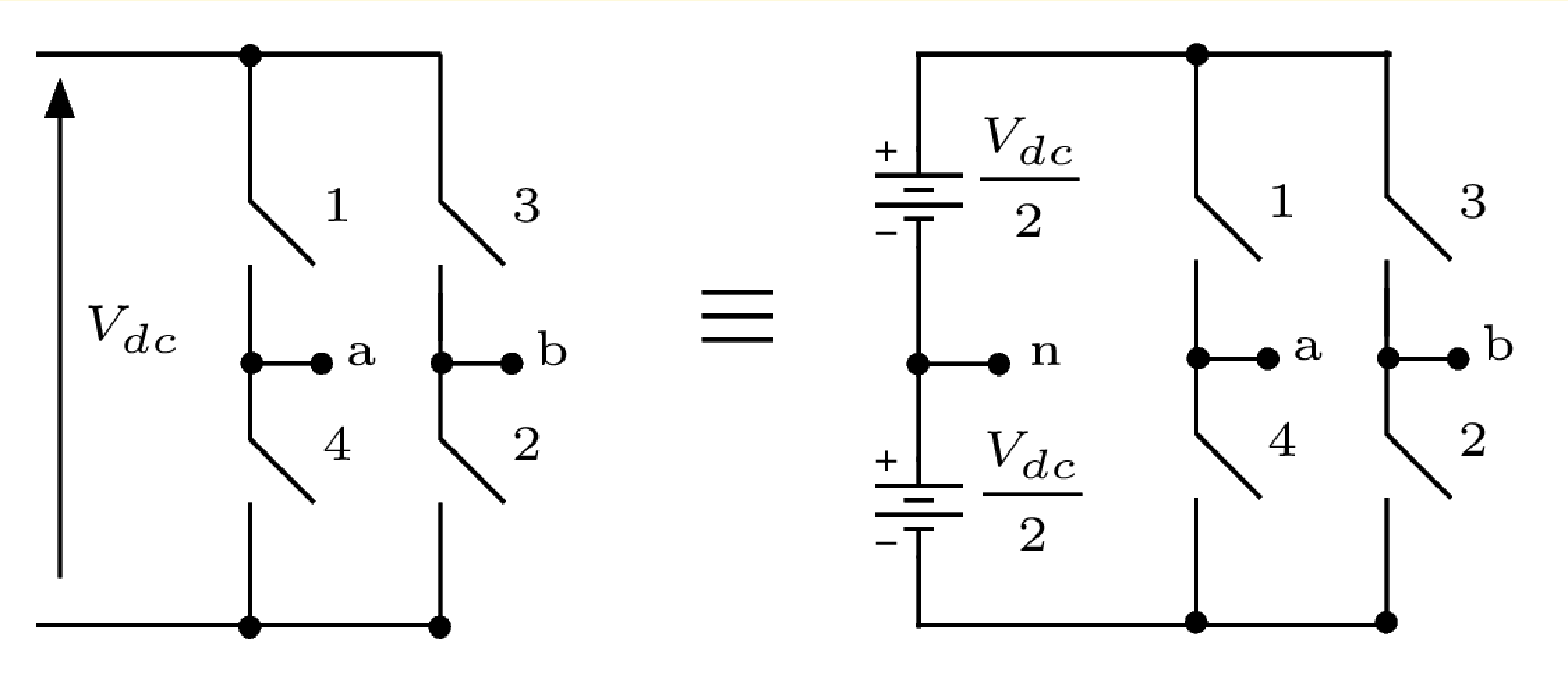
DC + Fundamental + harmonic components

Assuming $\mathbf{V_{dc}}$ is constant

Full bridge VSC

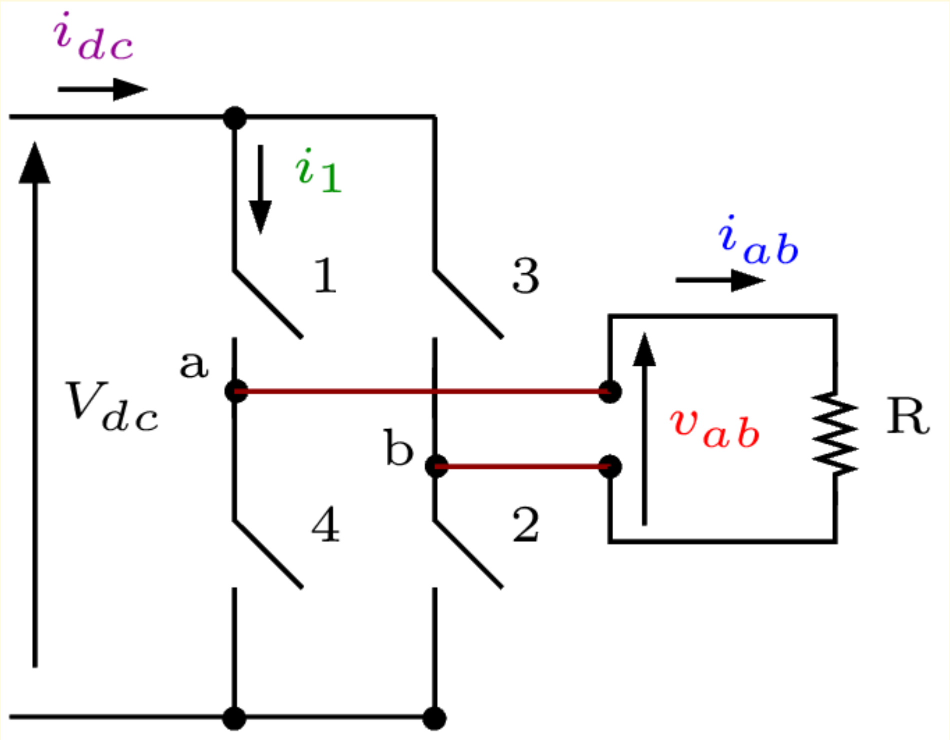


Full bridge VSC



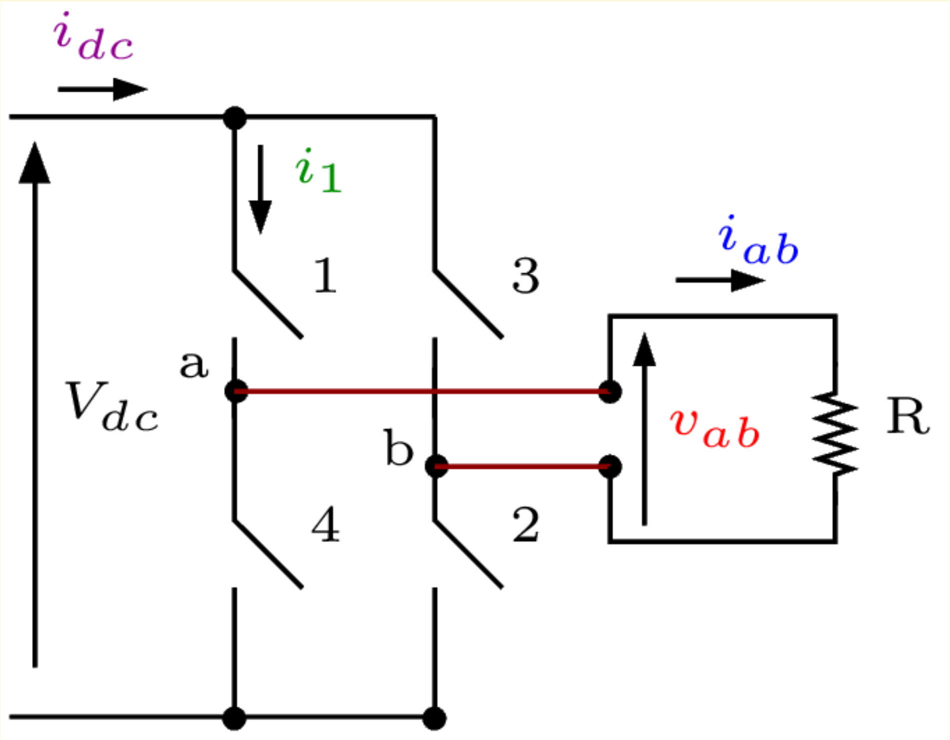
$$v_{ab} = v_{an} - v_{bn}$$

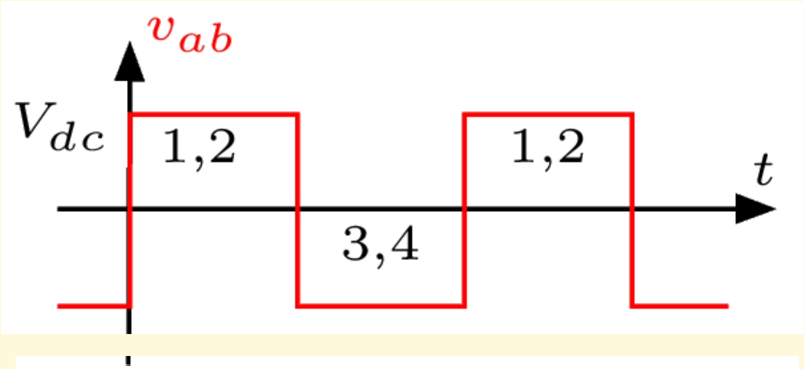
Full bridge VSC with **R** load

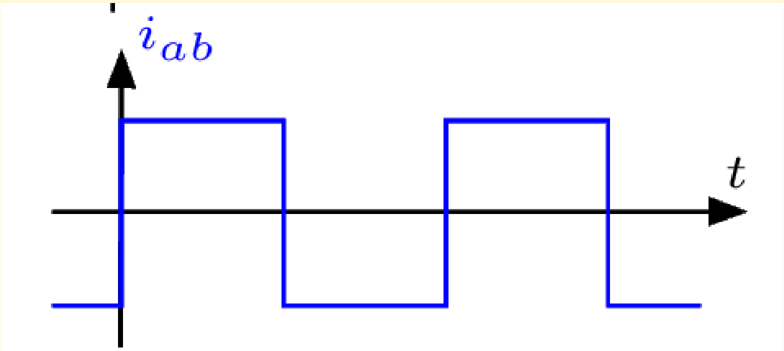


Assuming $\mathbf{V_{dc}}$ is constant

Full bridge VSC with **R** load

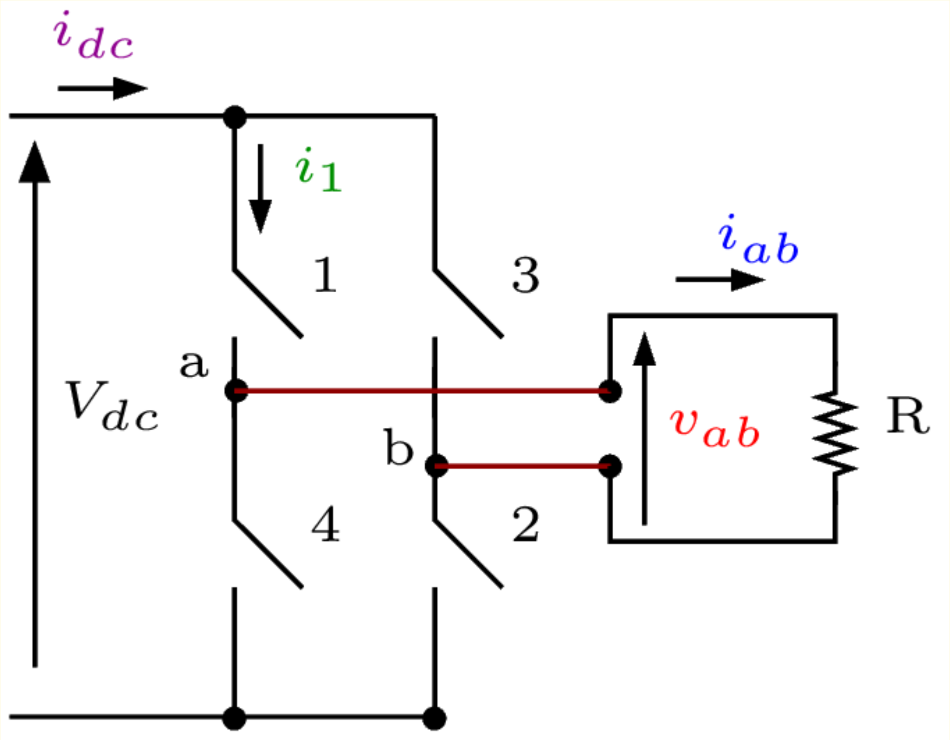


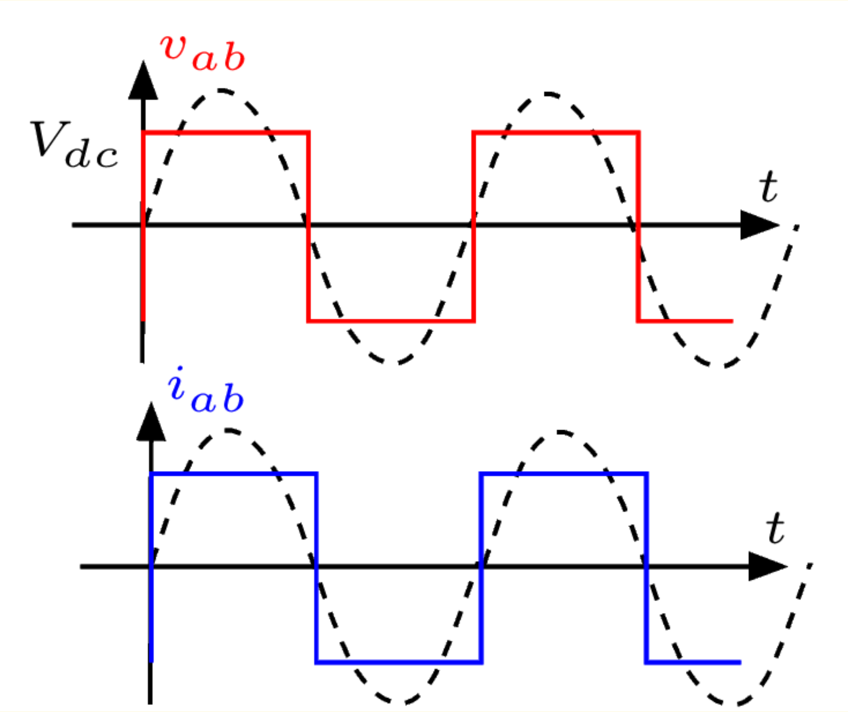




Assuming $\mathbf{V_{dc}}$ is constant

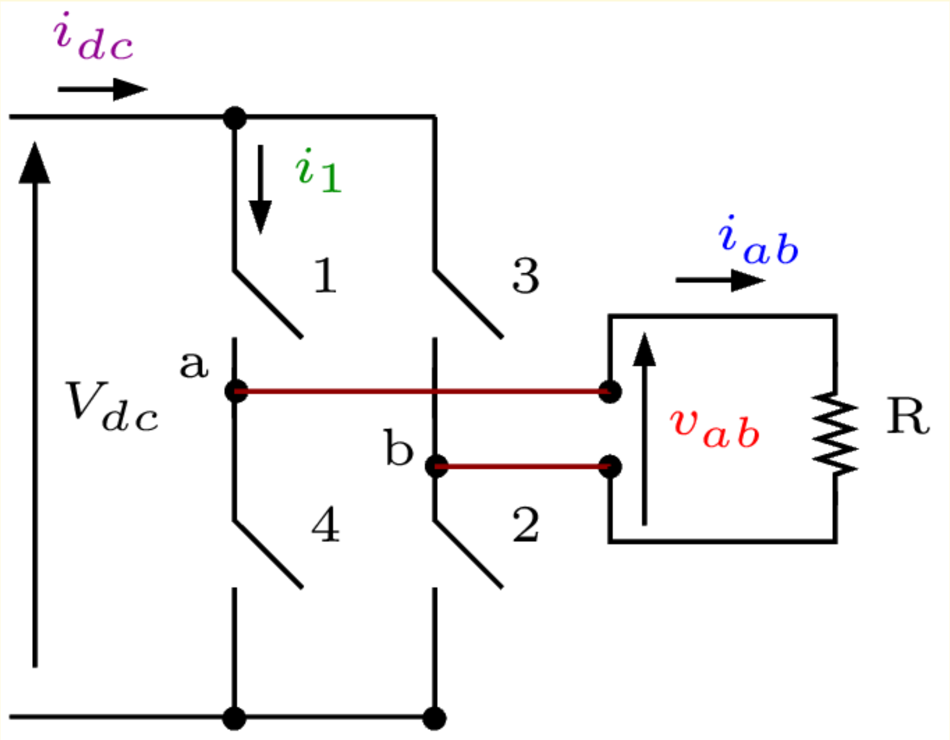
Full bridge VSC with **R** load

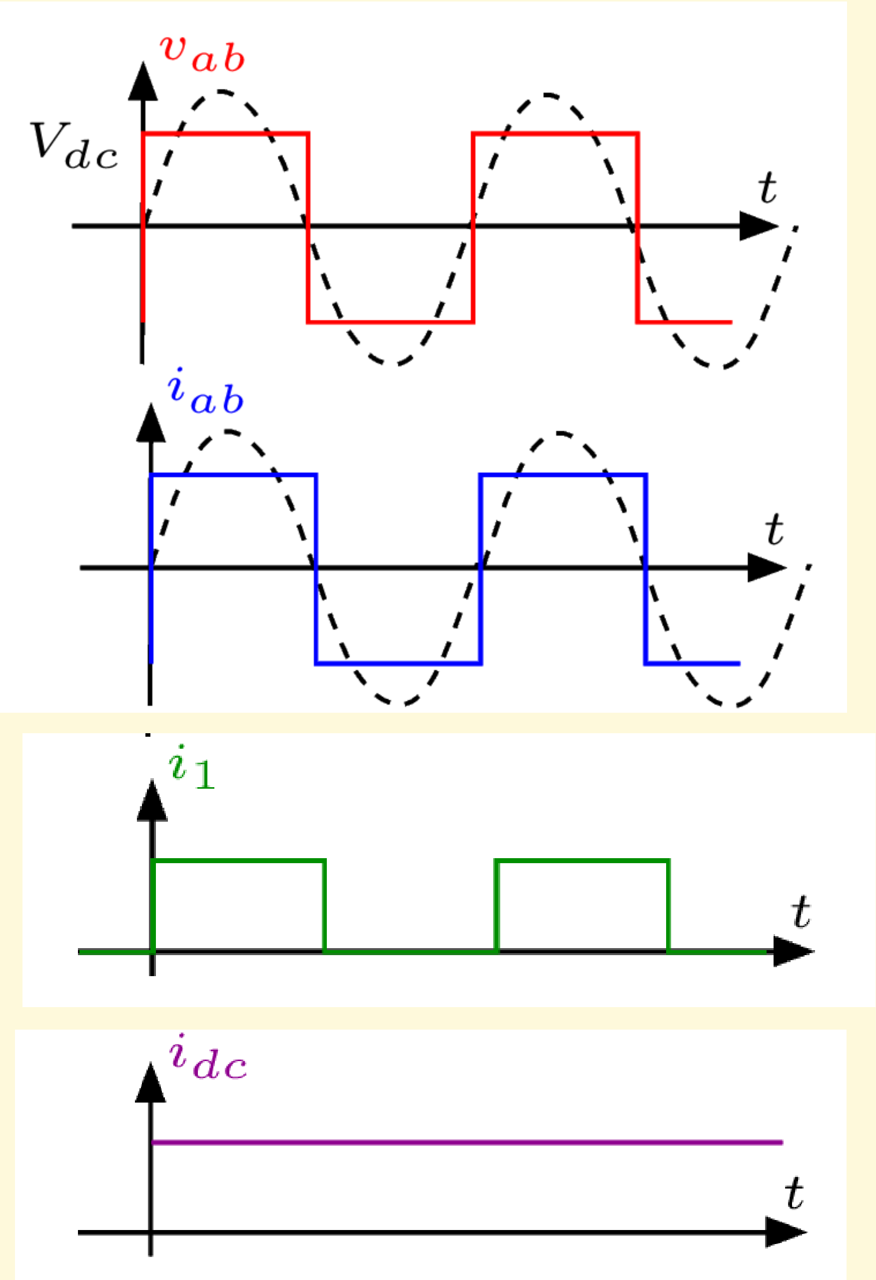




Assuming $\mathbf{V_{dc}}$ is constant

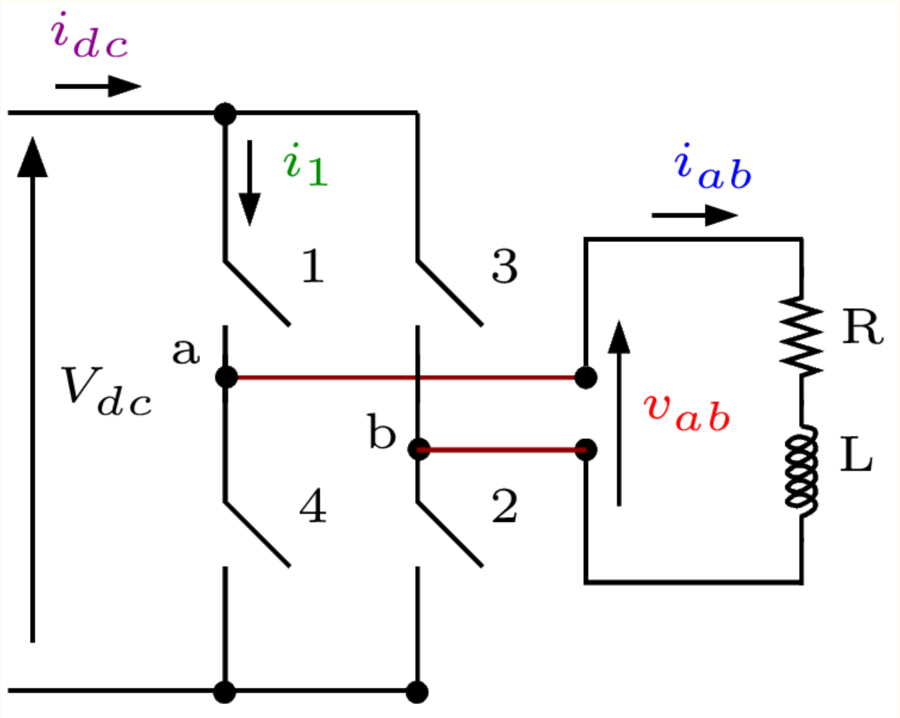
Full bridge VSC with **R** load



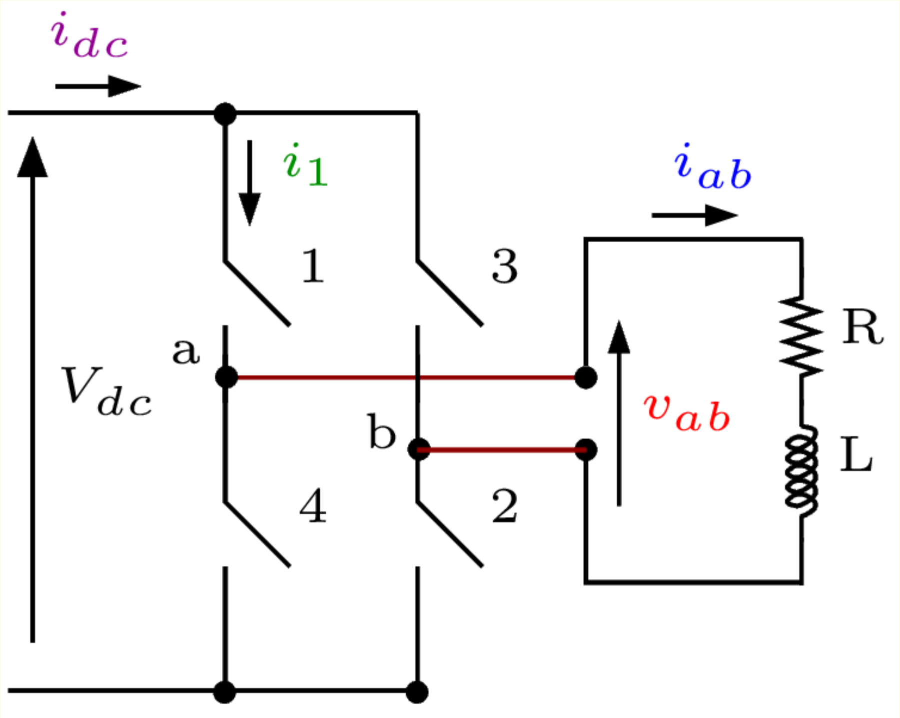


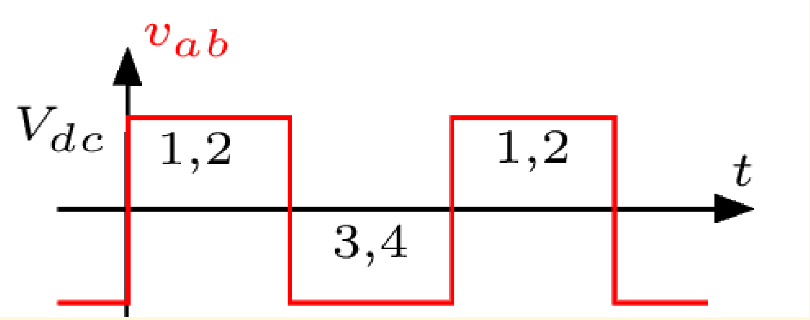
Assuming $\mathbf{V_{dc}}$ is constant

Full bridge VSC with **RL** load

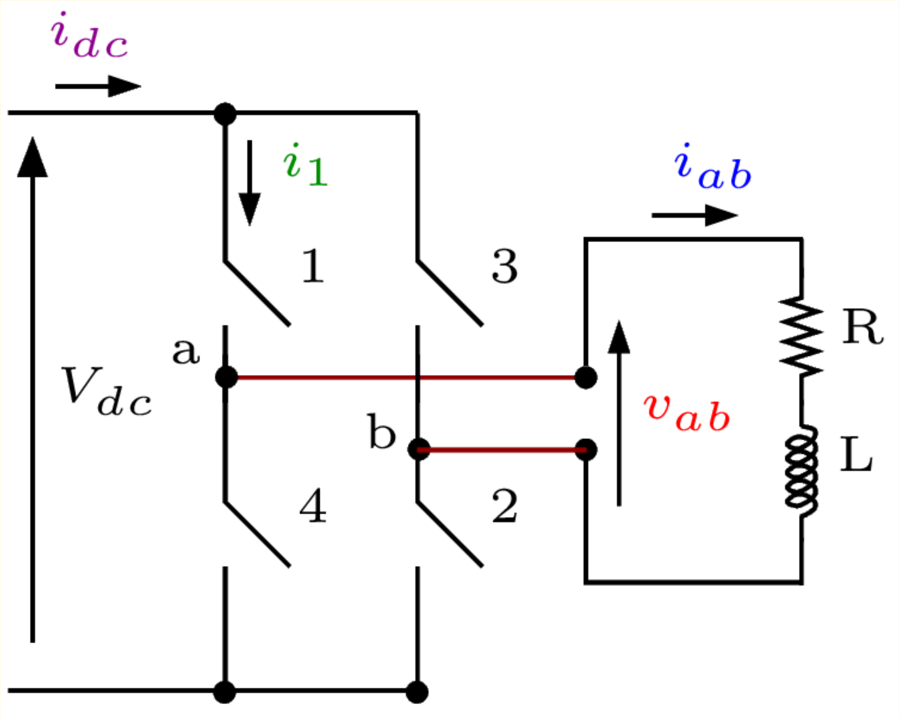


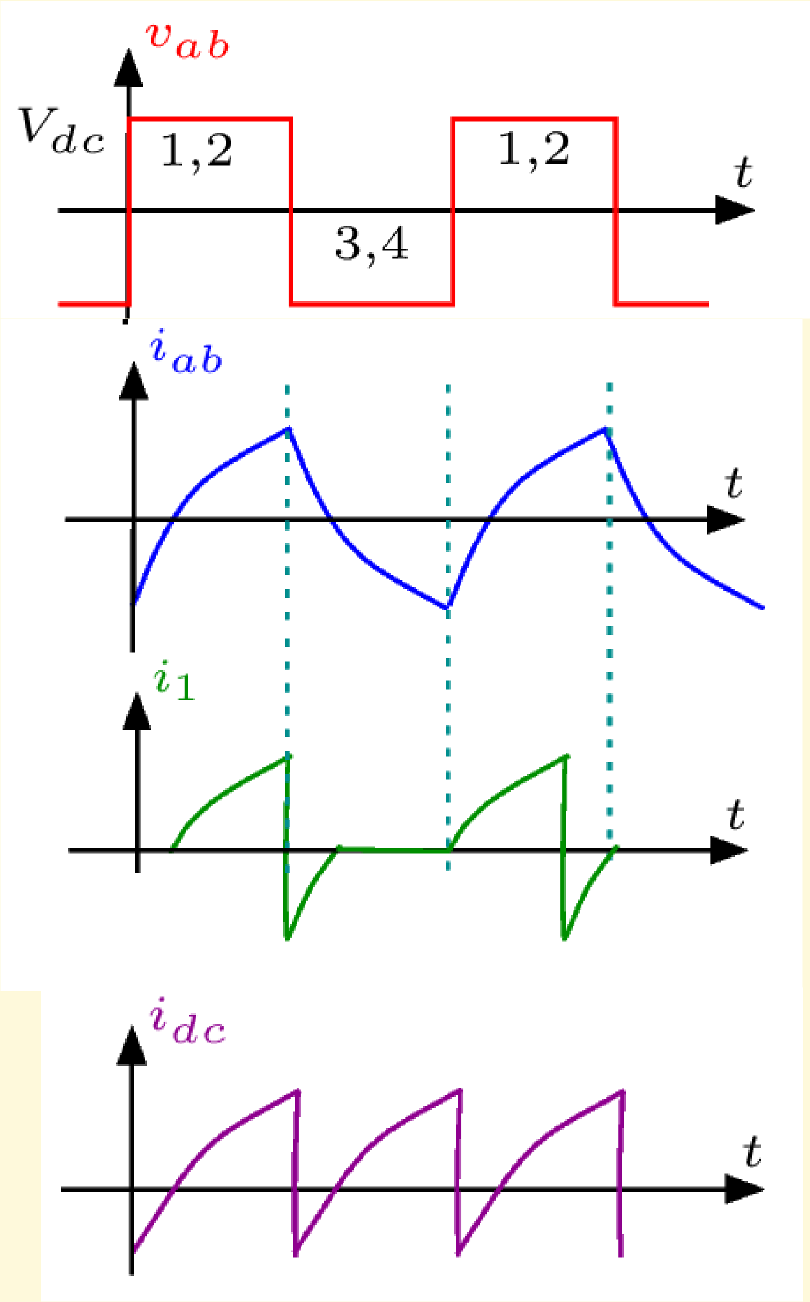
Full bridge VSC with **RL** load



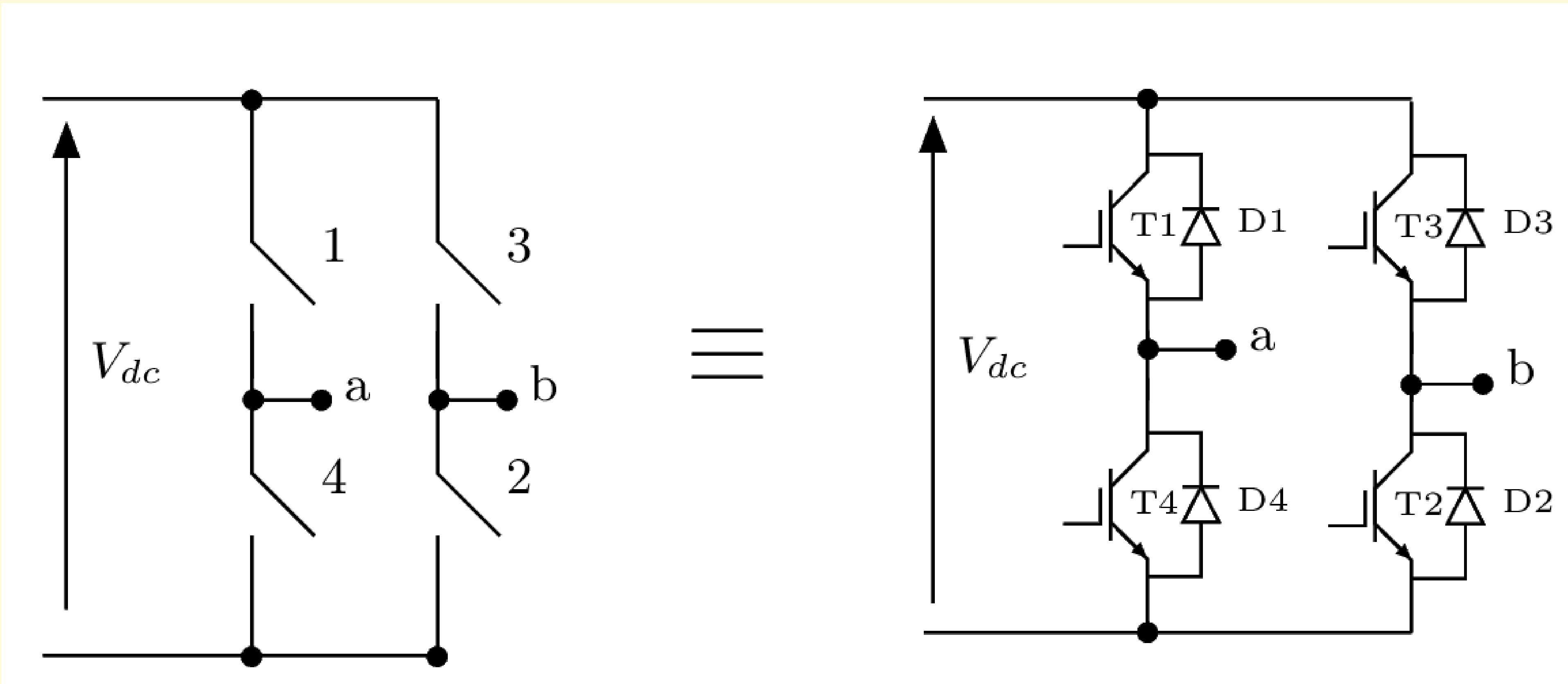


Full bridge VSC with **RL** load

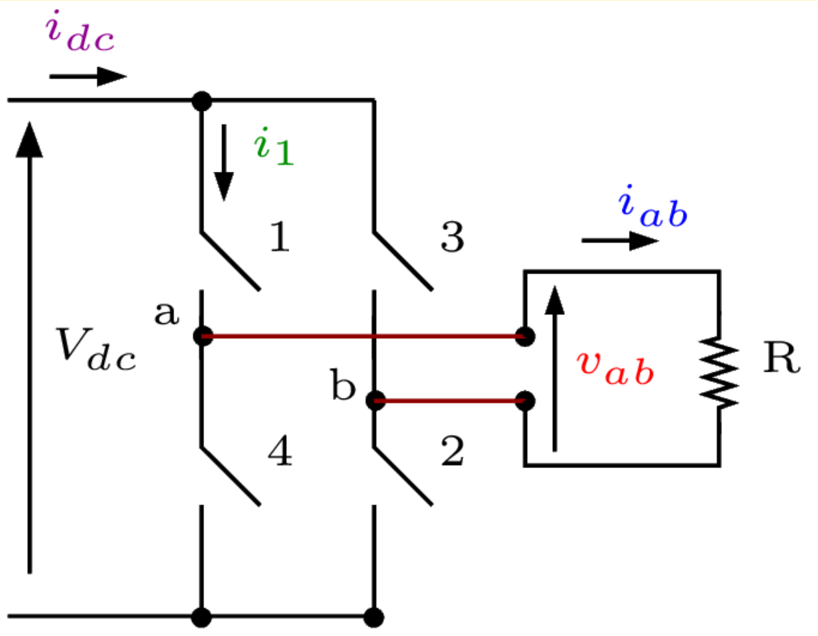


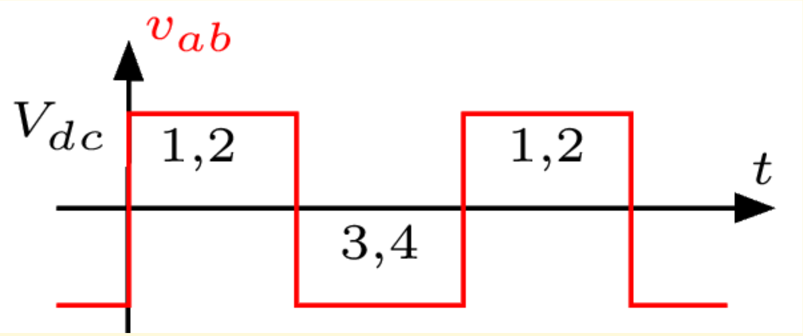


Note: two level full bridge VSC is realized as:

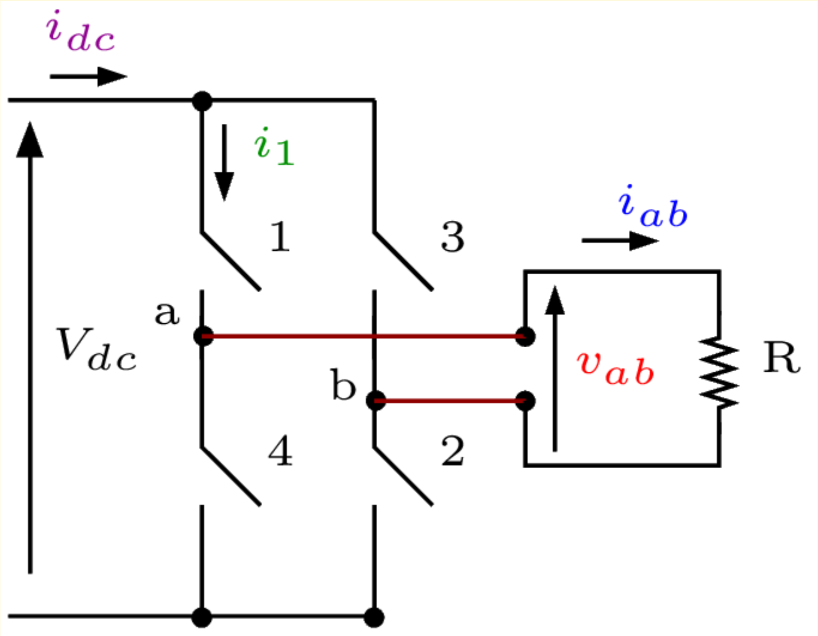


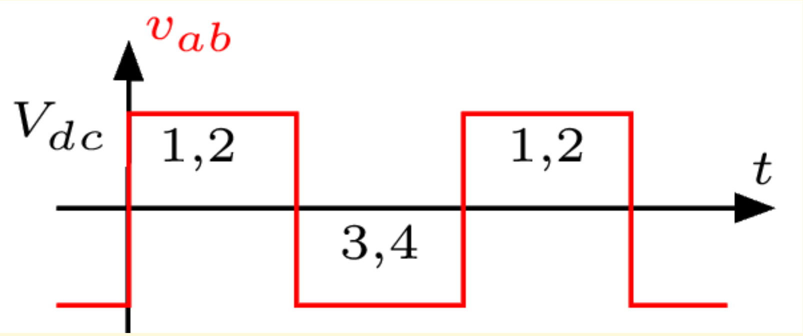
Full bridge VSC (harmonic elimination)

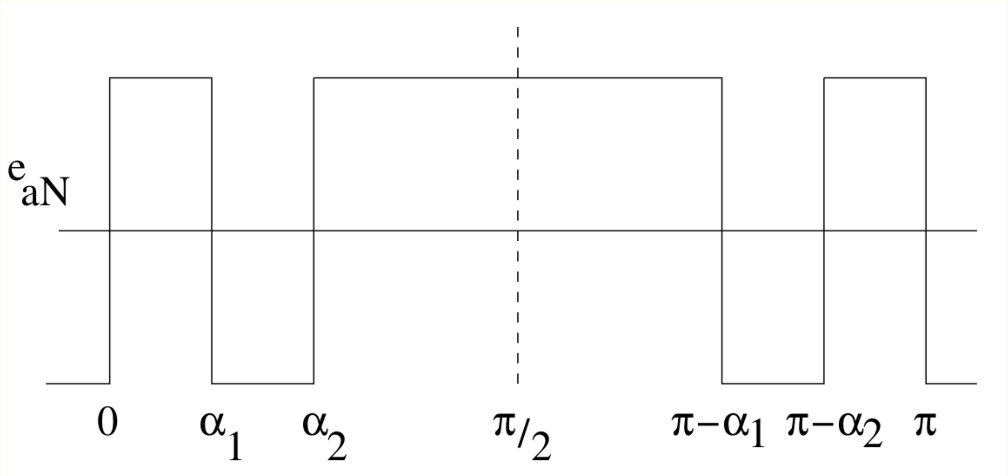




Full bridge VSC (harmonic elimination)



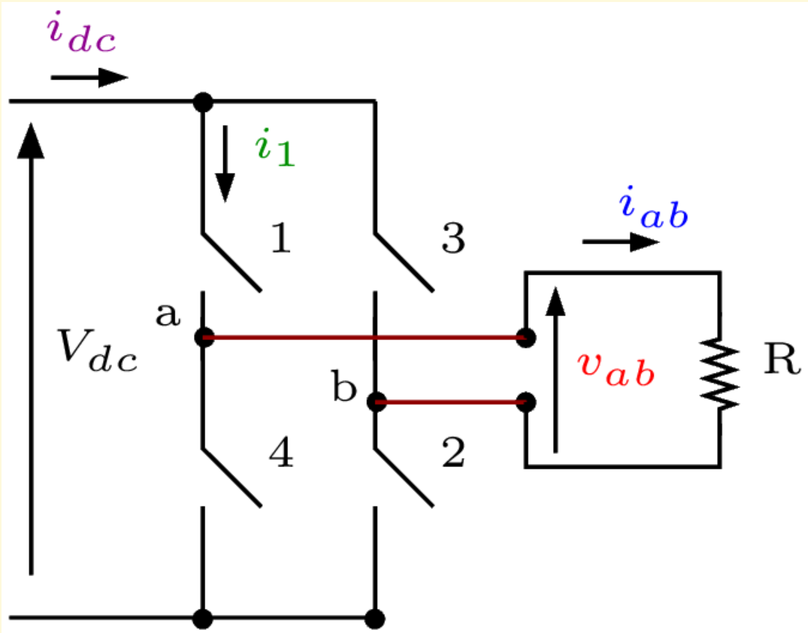


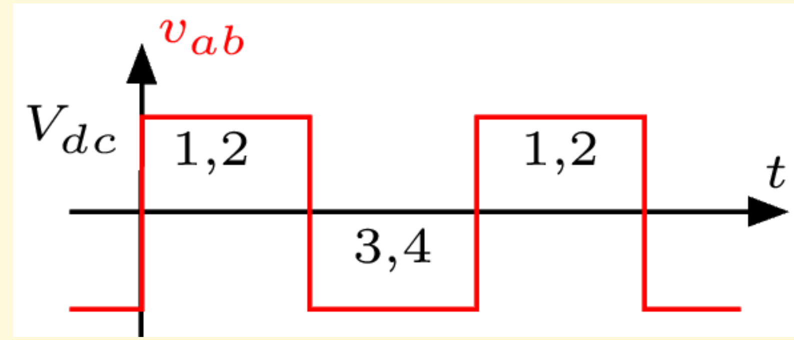


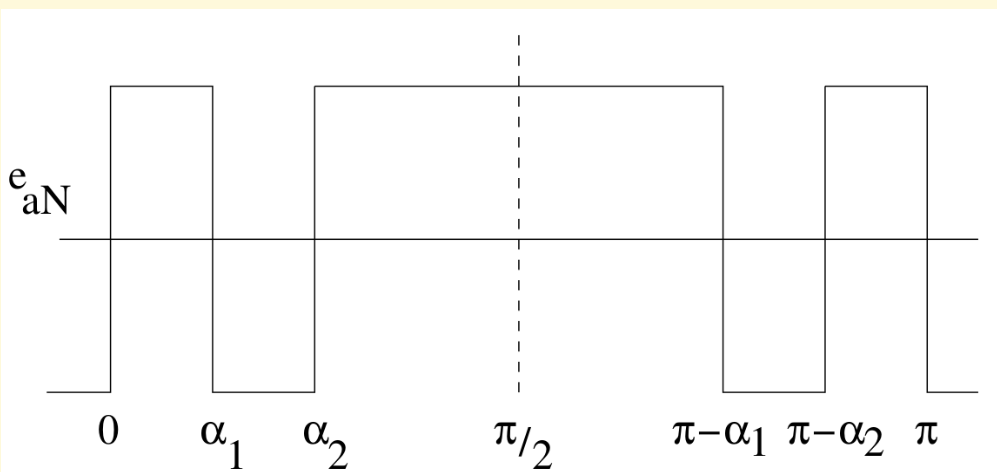
4 voltage reversals in a half cycle

Source: K. R. Padiyar, *FACTS controllers in power transmission and distribution,* New Age publication, 2007.

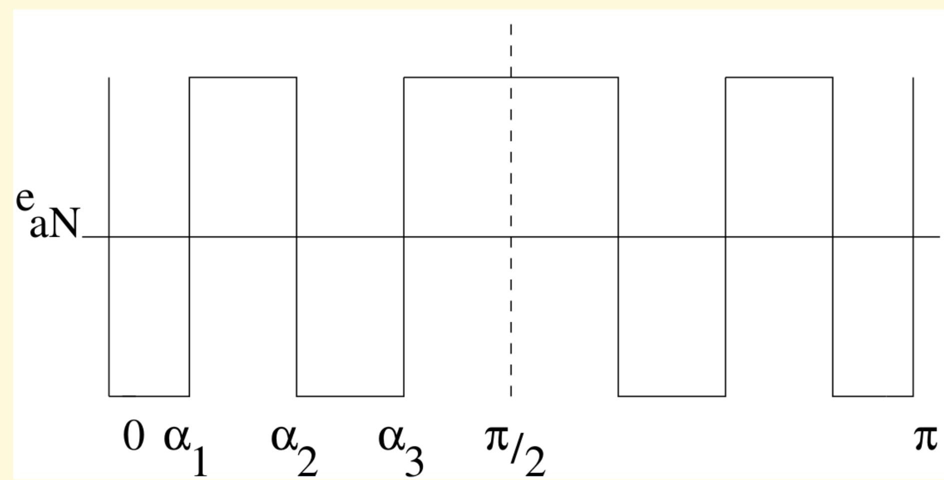
Full bridge VSC (harmonic elimination)







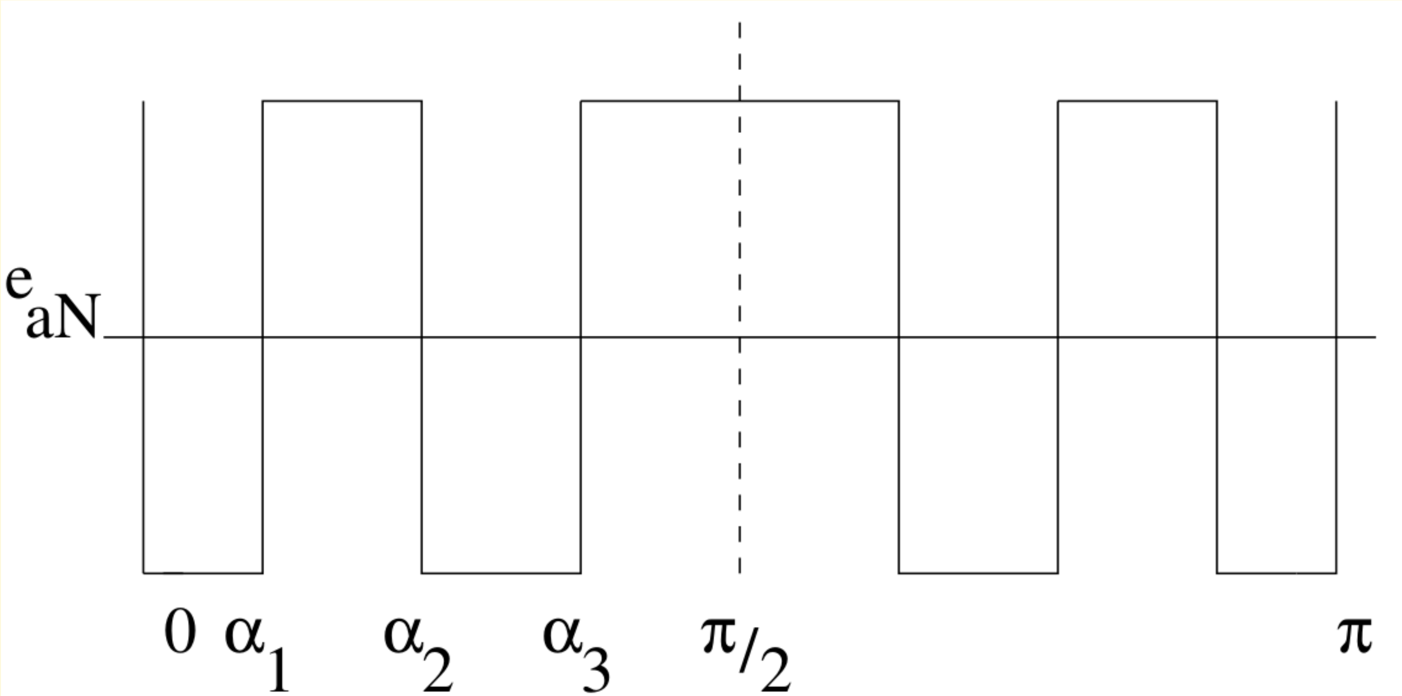
4 voltage reversals in a half cycle



6 voltage reversals in a half cycle

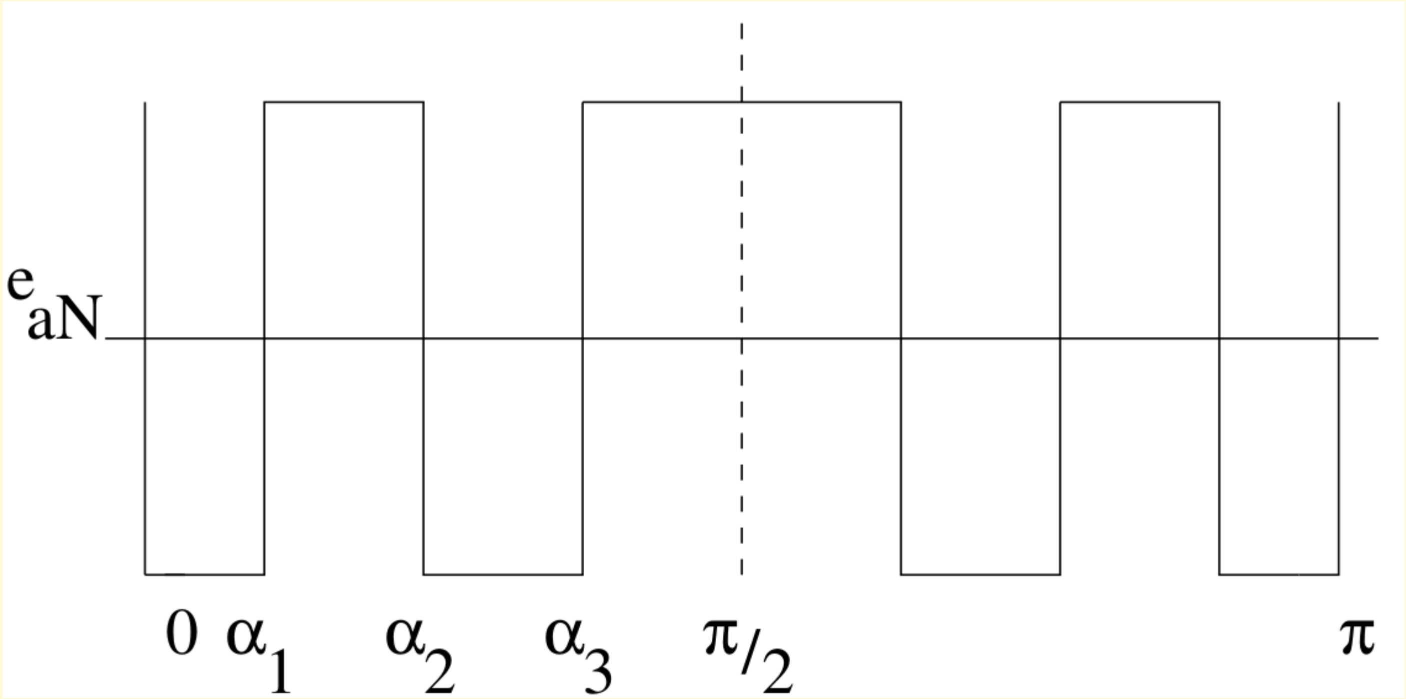
Full bridge VSC

Consider



Full bridge VSC

Consider



The switching angles are estimated using numerical methods:

$$
\begin{aligned}
\bar{m} &= 2[\cos\alpha_1 - \cos\alpha_2 + \cos\alpha_3] - 1 \\
0 &= 2[\cos 5\alpha_1 - \cos 5\alpha_2 + \cos 5\alpha_3] - 1 \\
0 &= 2[\cos 7\alpha_1 - \cos 7\alpha_2 + \cos 7\alpha_3] - 1
\end{aligned}
$$

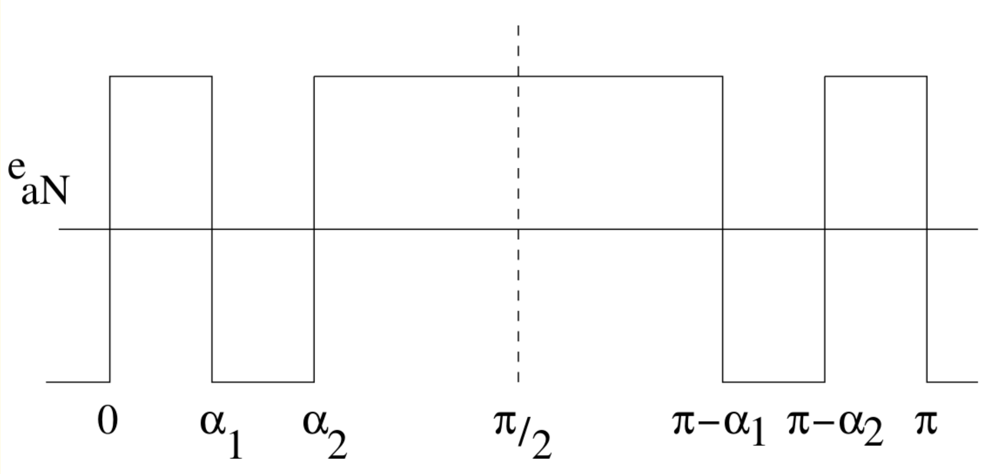
Full bridge VSC

Example:

If there are two voltage reversals in a quarter cycle, the values of α_1 and α_2 for eliminating 5^{th} and 7^{th} voltage harmonic are

$\alpha_1 = 16.2^o$

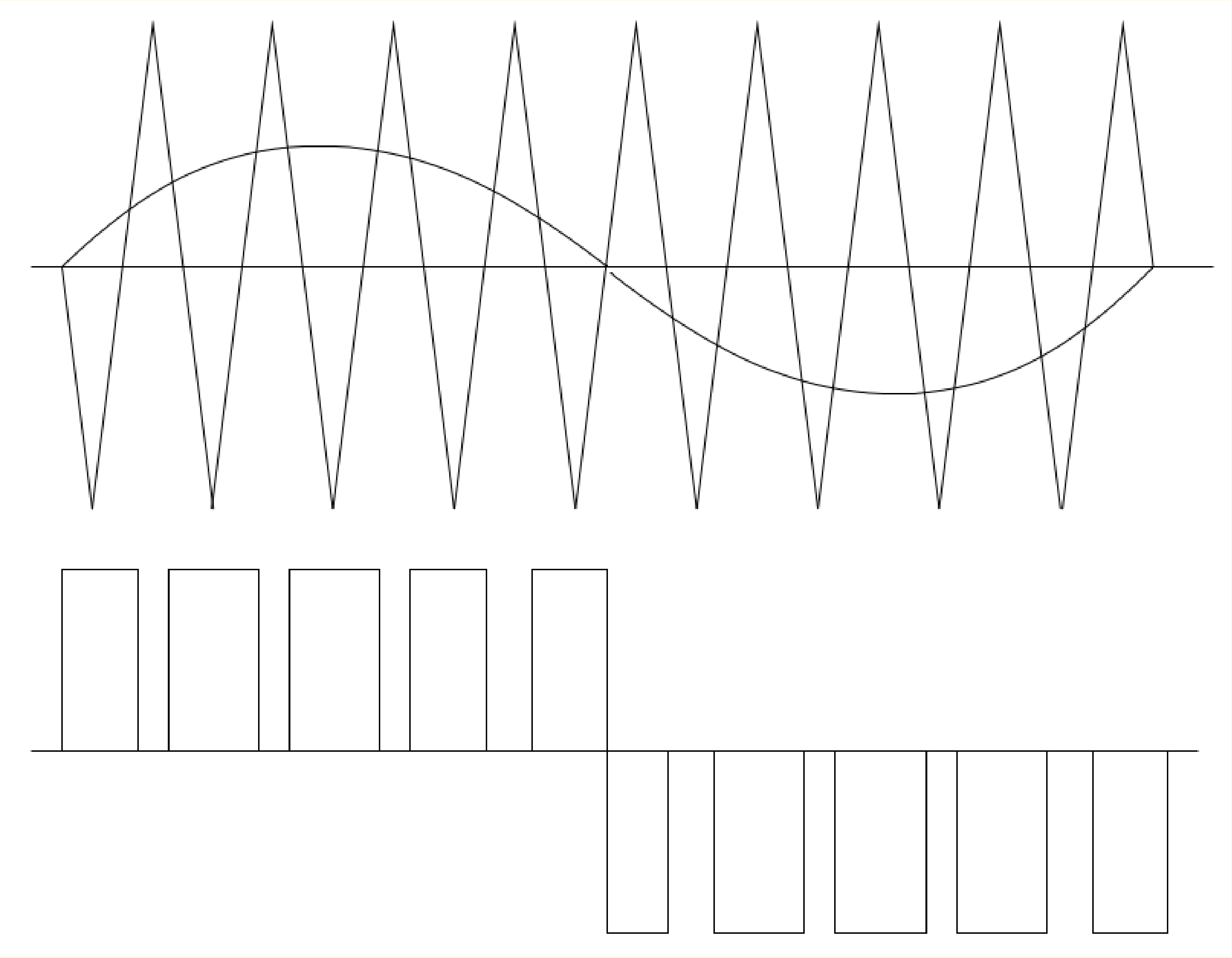
$\alpha_2 = 22^o$



The modulation index is:

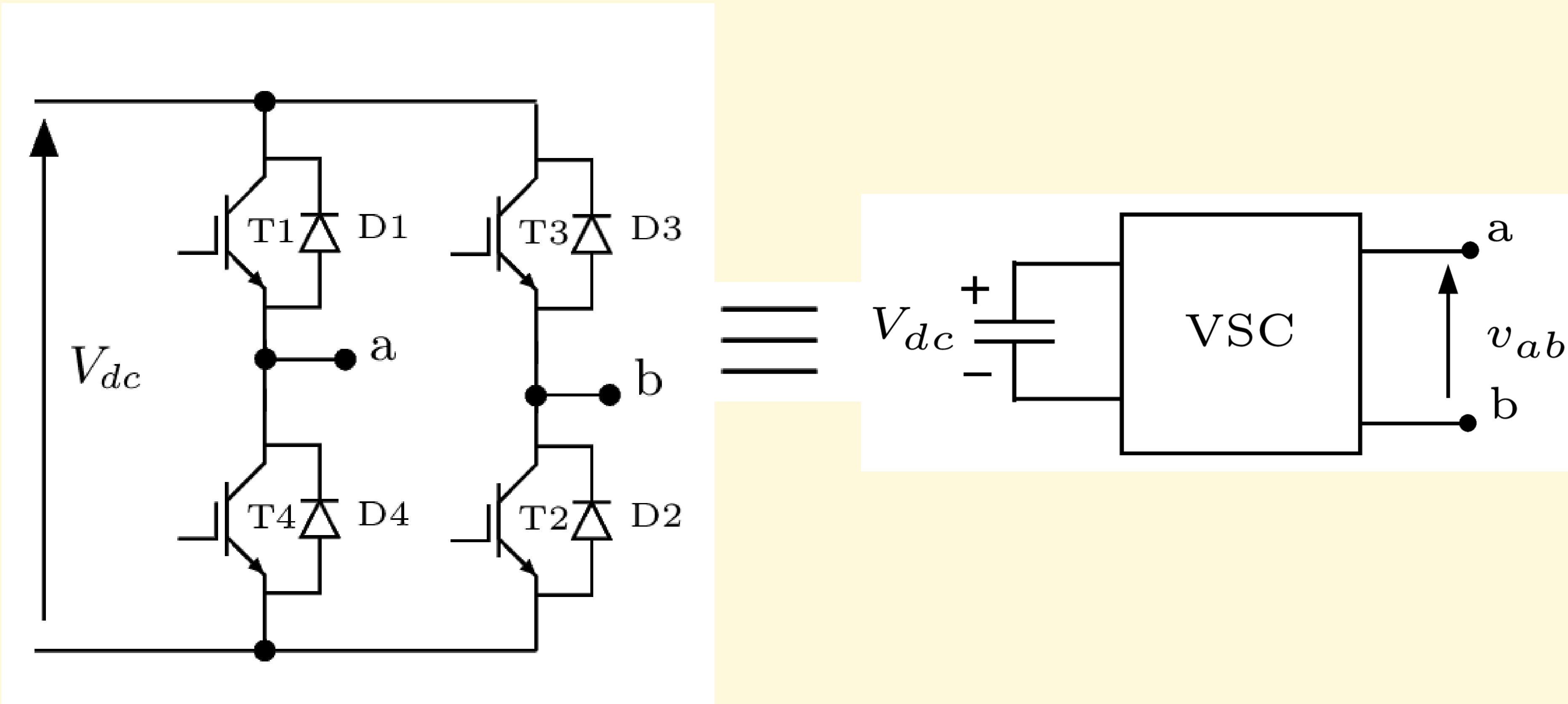
$$\bar{m} = 1 - 2(\cos\alpha_1 - \cos\alpha_2) = 0.934$$

Full bridge VSC

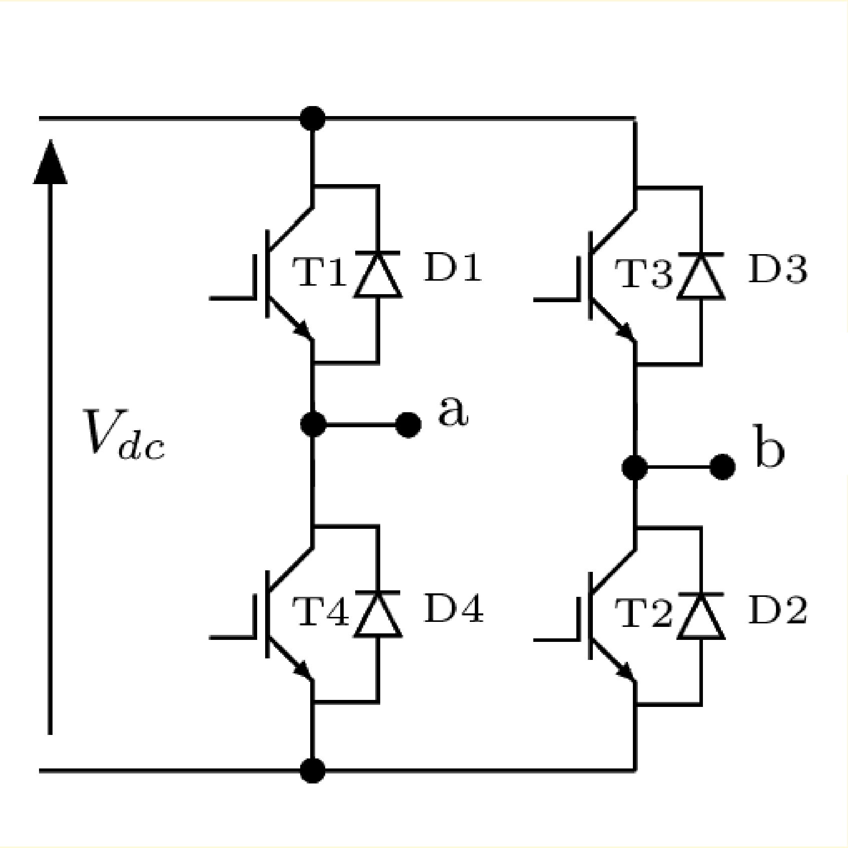


Sine triangle PWM

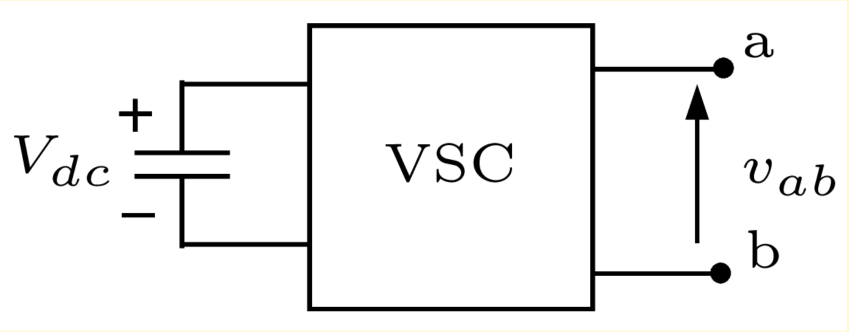
VSC block equivalent



VSC block equivalent

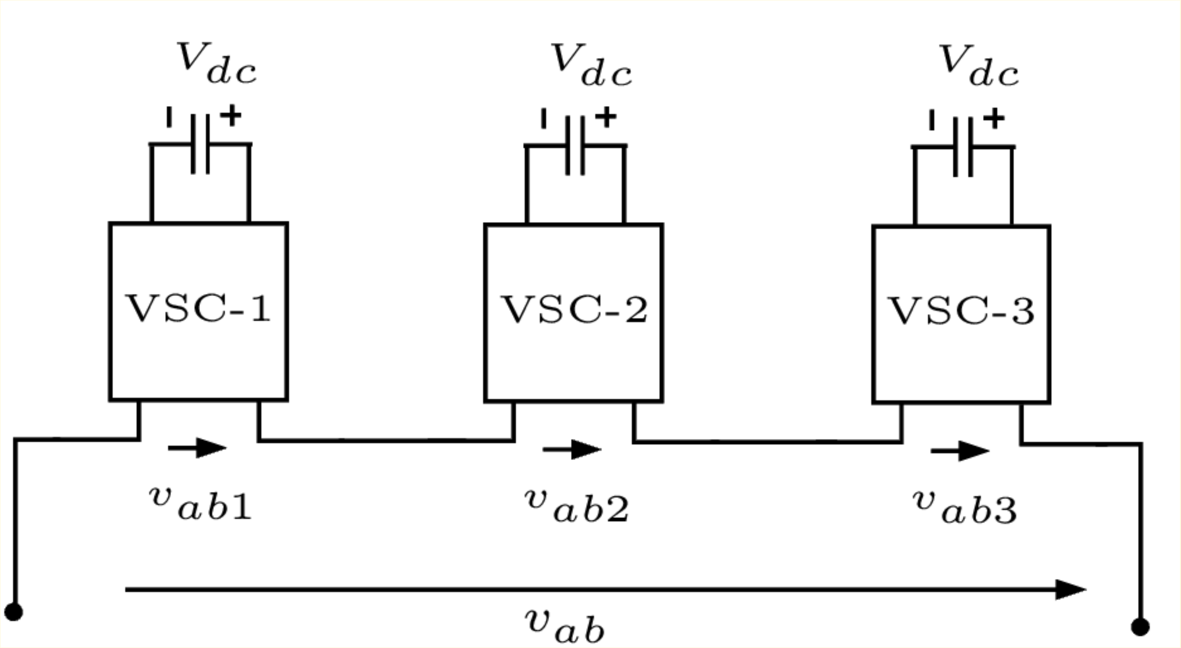


$\equiv$

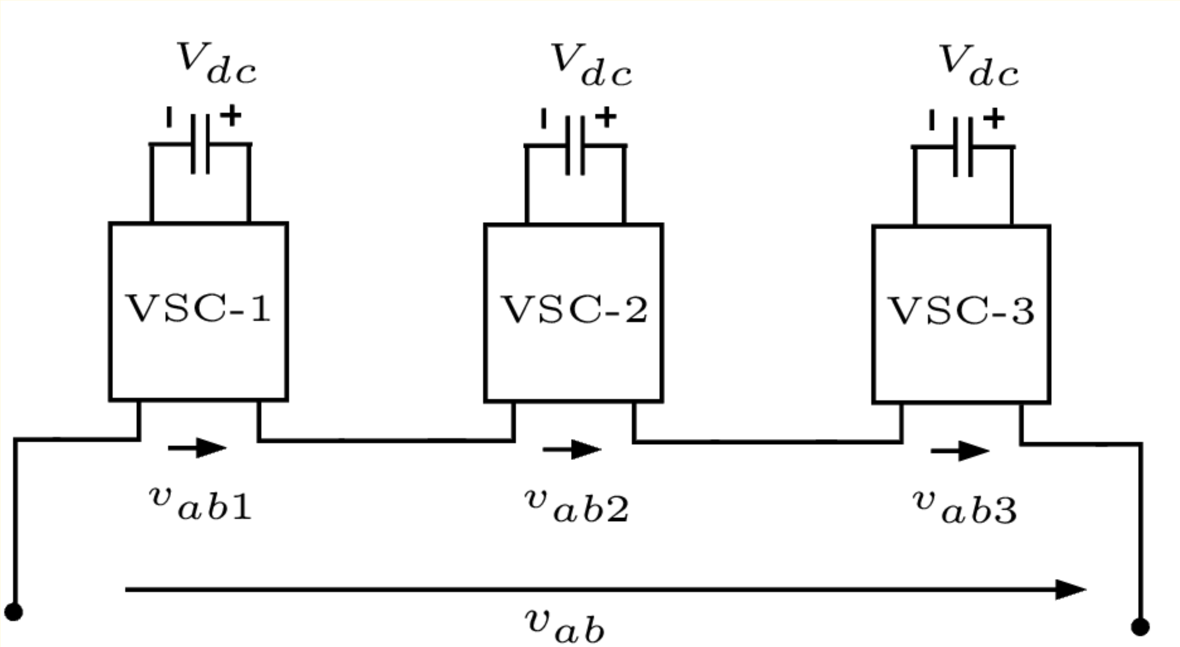


Possible output levels: **+V_{dc}, 0, -V_{dc}**

Modular multilevel converters (MMCs)



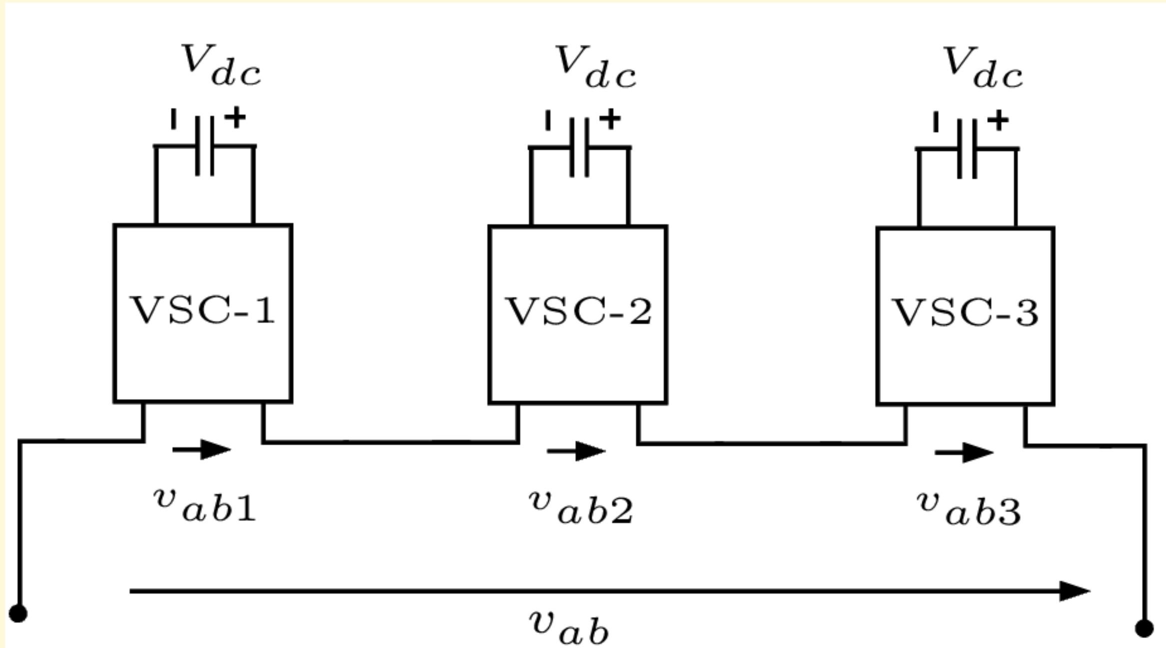
Modular multilevel converters (MMCs)

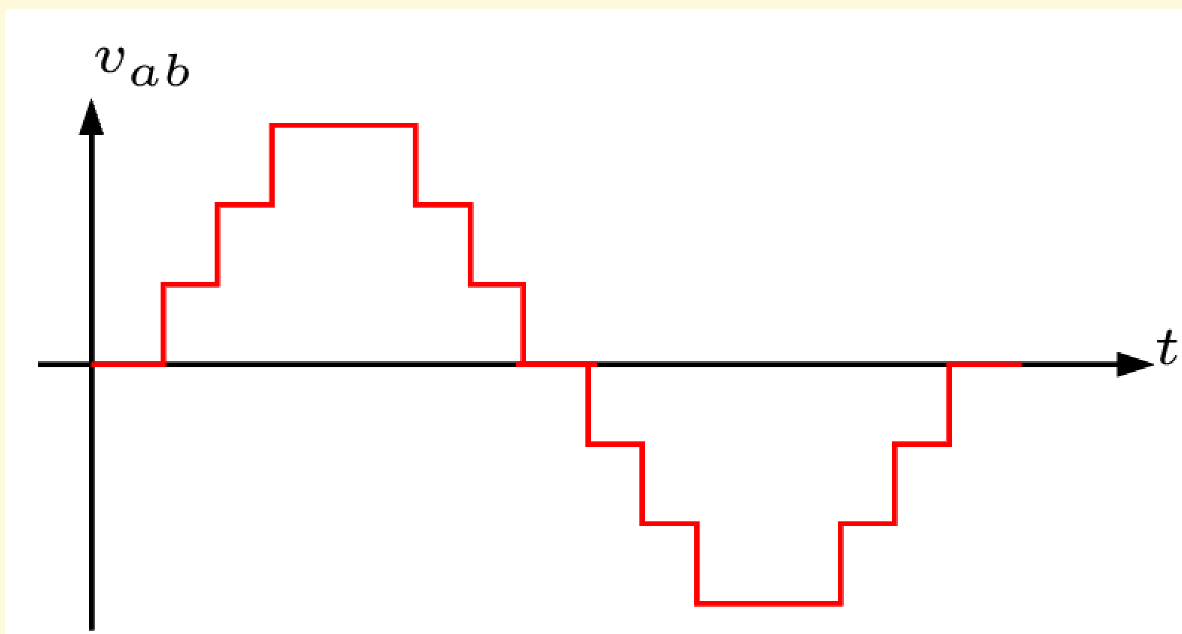


Possible output levels:

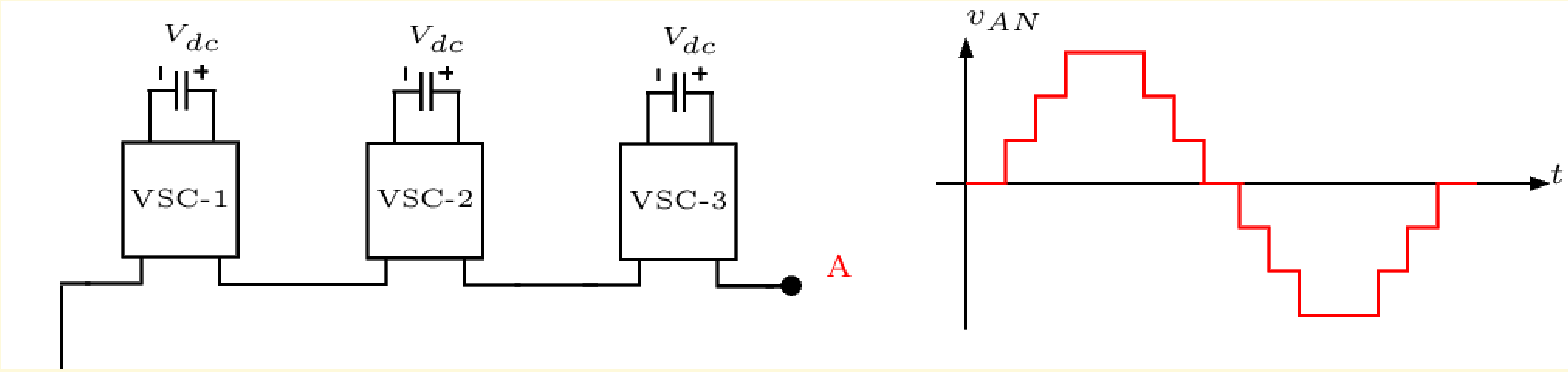
$+3V_{dc}$, $+2V_{dc}$, $+V_{dc}$, 0, $-V_{dc}$, $-2V_{dc}$, $-3V_{dc}$

Modular multilevel converters (MMCs)

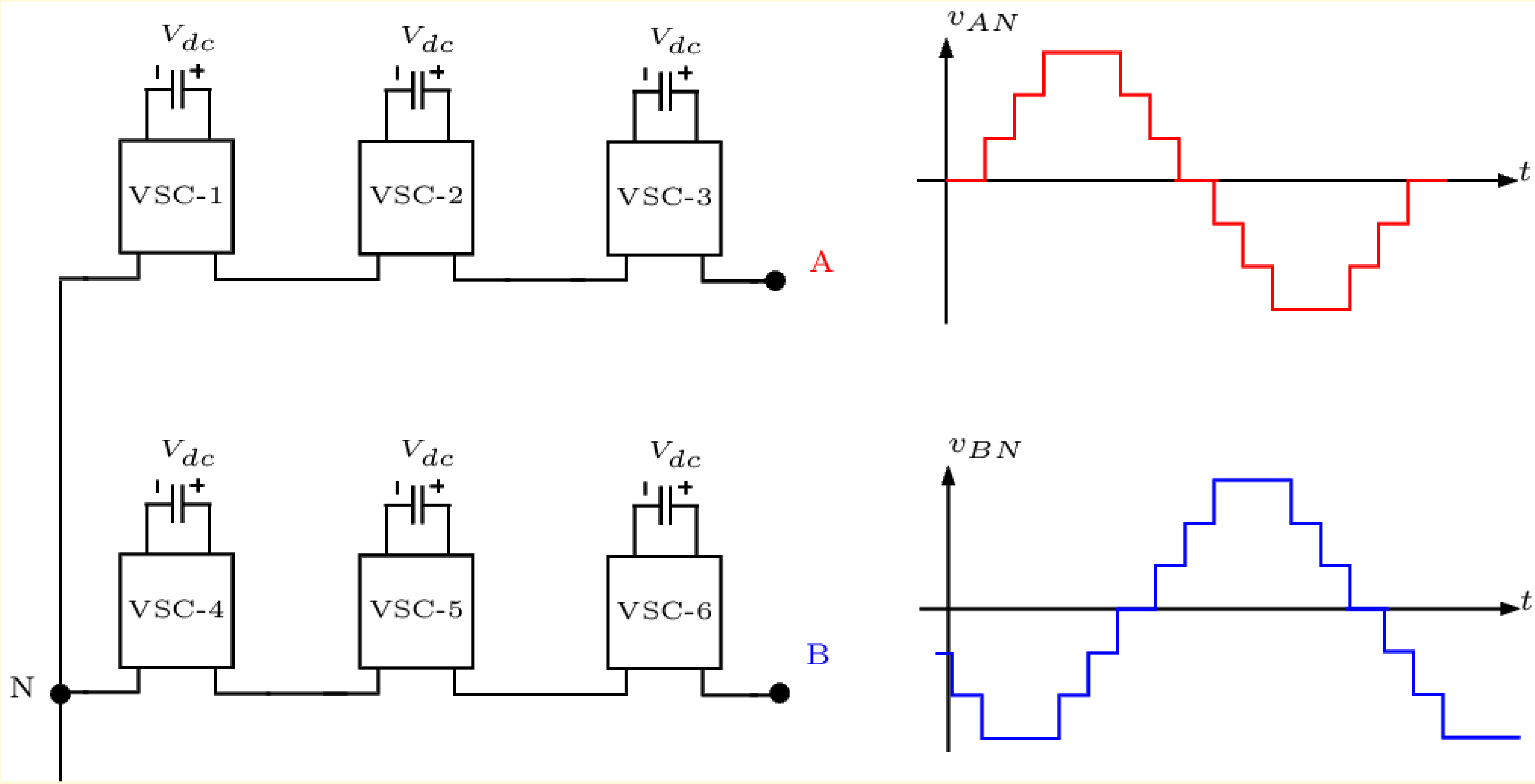




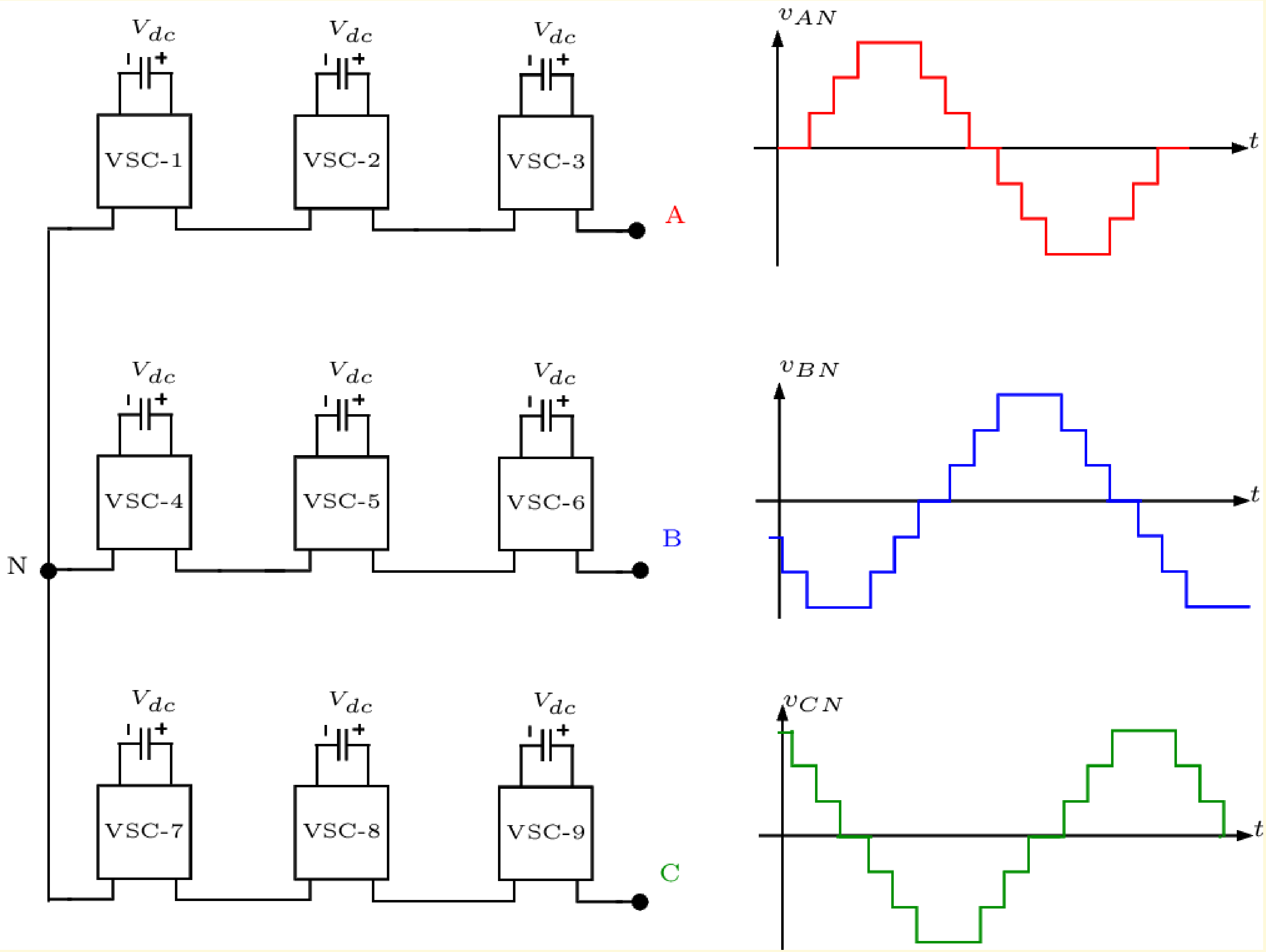
Modular multilevel converters (MMCs)



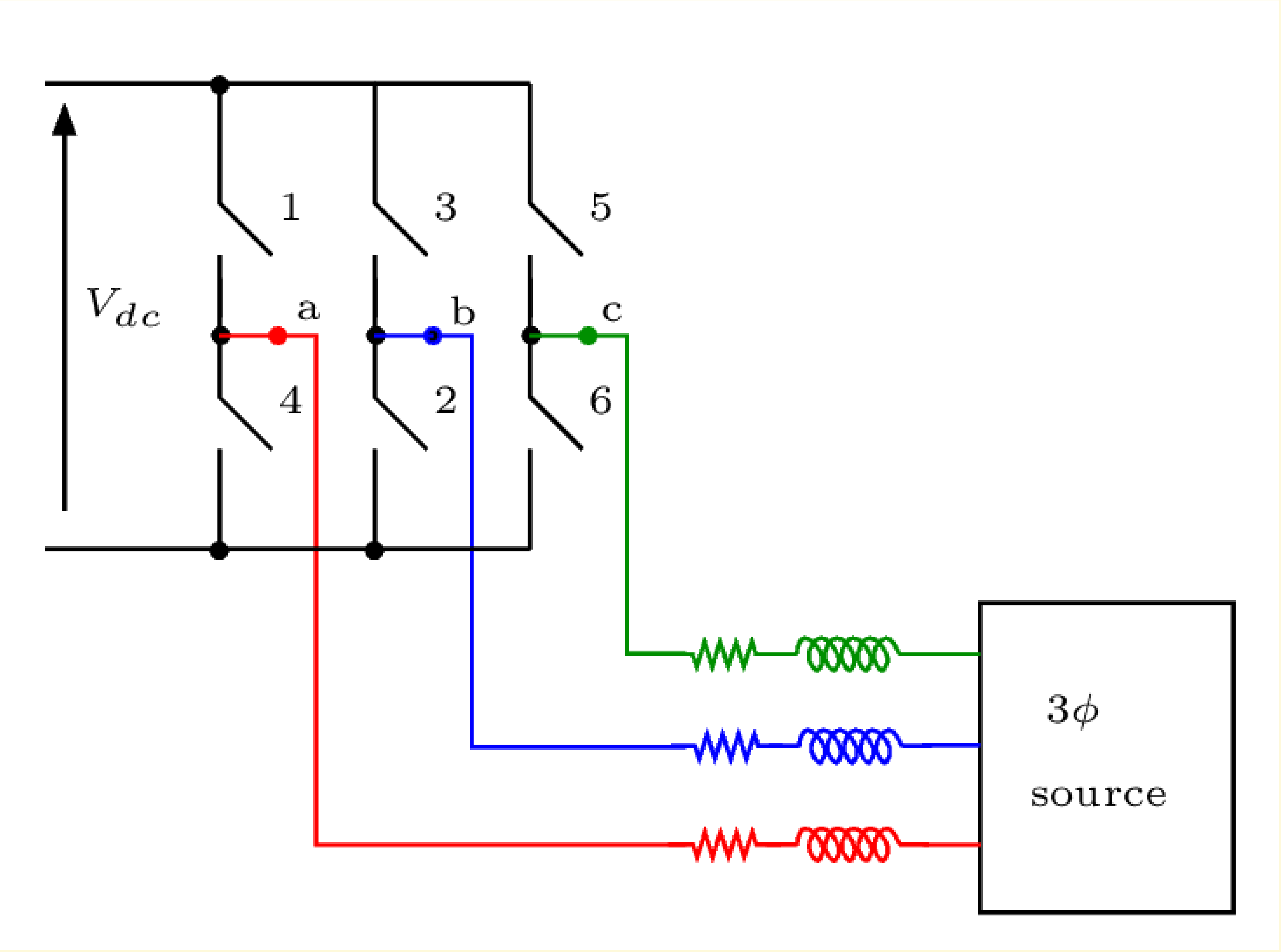
Modular multilevel converters (MMCs)



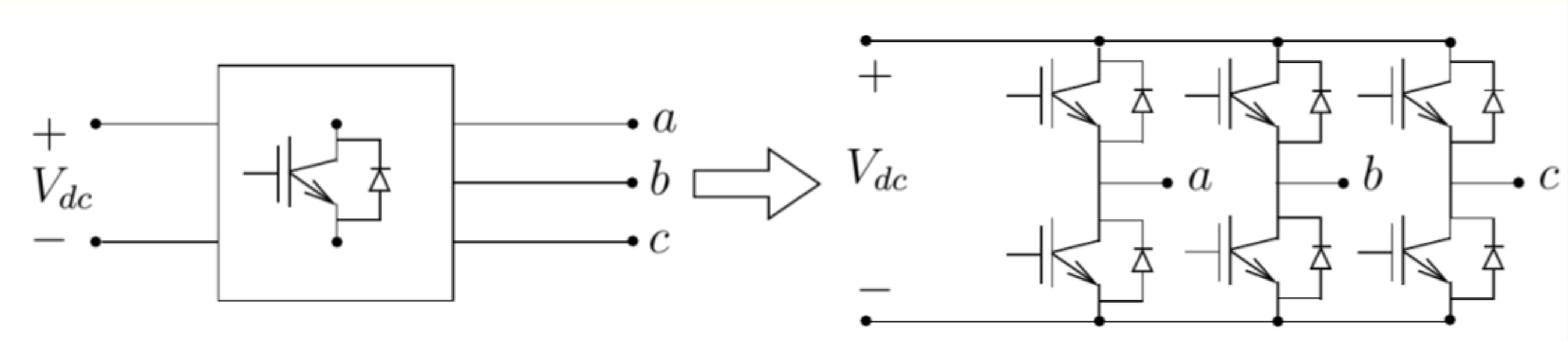
Modular multilevel converters (MMCs)



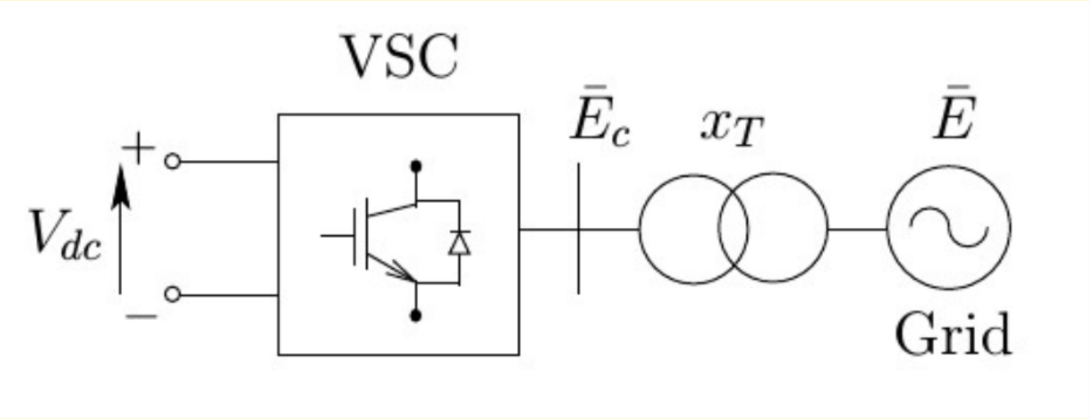
Three-phase two level bridge circuit



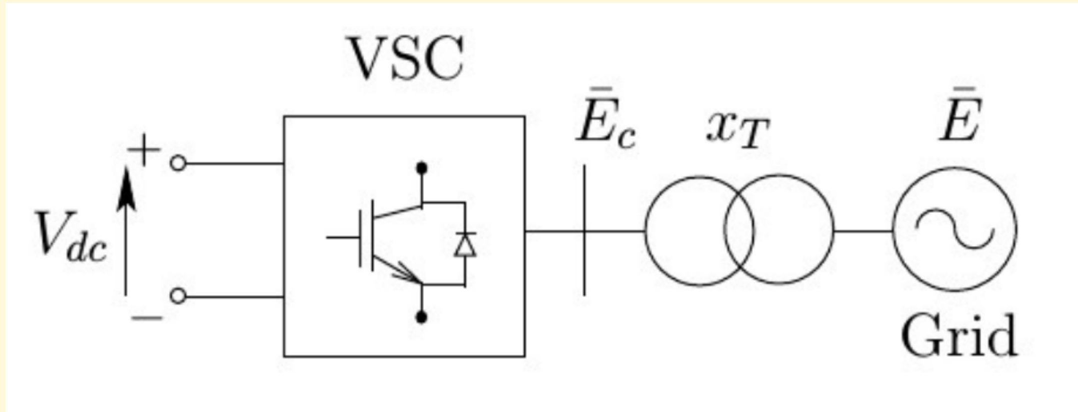
Three-phase two level bridge circuit

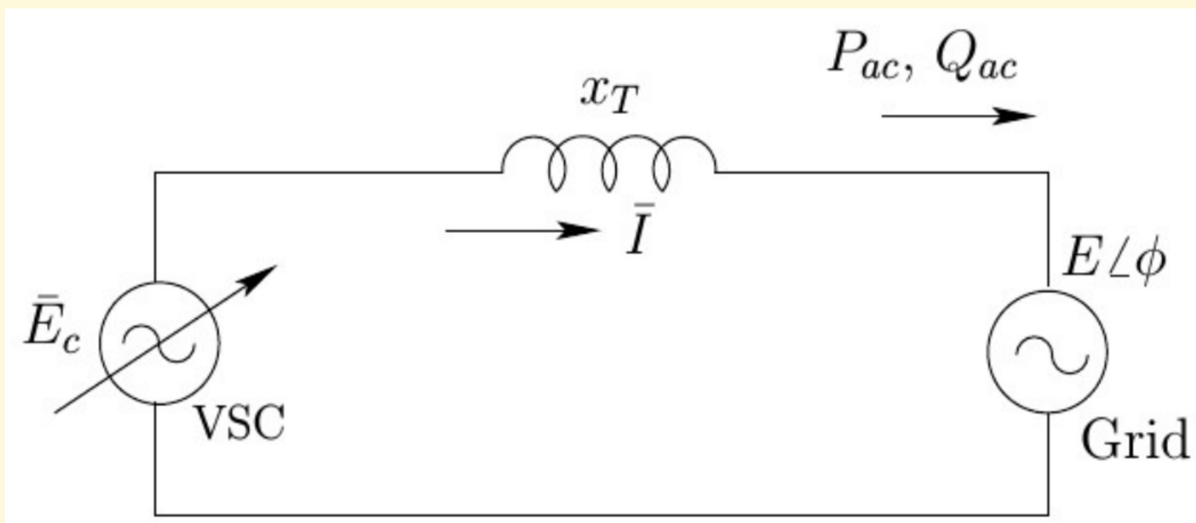


VSC Connected to Grid



VSC Connected to Grid

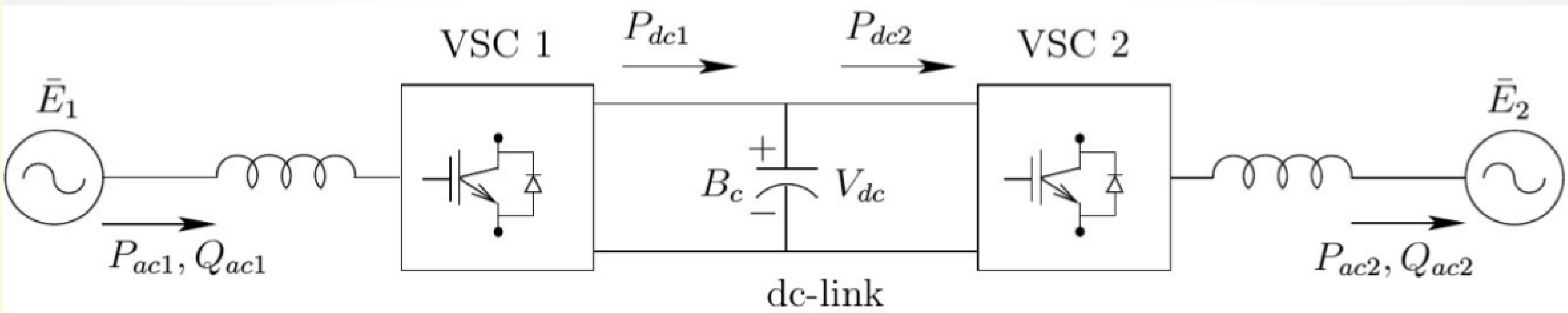




(1) $\bar{E}_c = mV_{dc}\angle(\phi + \alpha)$

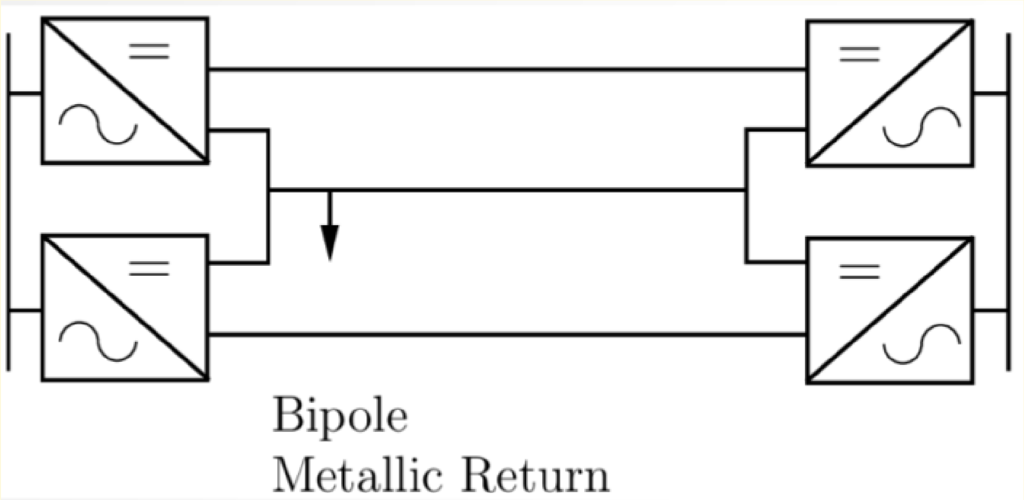
(2) m and α are independently controllable

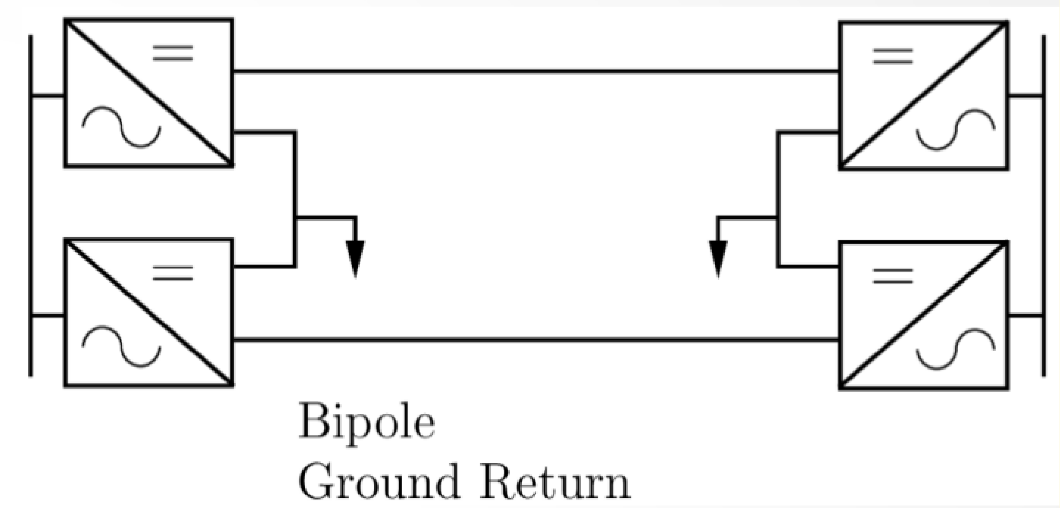
Example: Monopolar HVDC link



(1) P_{ac1}=P_{dc1}, P_{ac2} =P_{dc2} (loss-less converter)
(2) P_{dc1}=P_{dc2} in steady state
(3) Q_{ac1}, Q_{ac2} are independently controllable

HVDC Configurations





HVDC Configurations