Grid integration of offshore wind farms using HVDC links: HVDC-VSC technology overview

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Introduction

OWPP layouts

HVDC-VSC technology overview

- Two level converters.
- Three level NPC converters
- Modular multilevel converters

Conclusions

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Transmission layouts for OWPP

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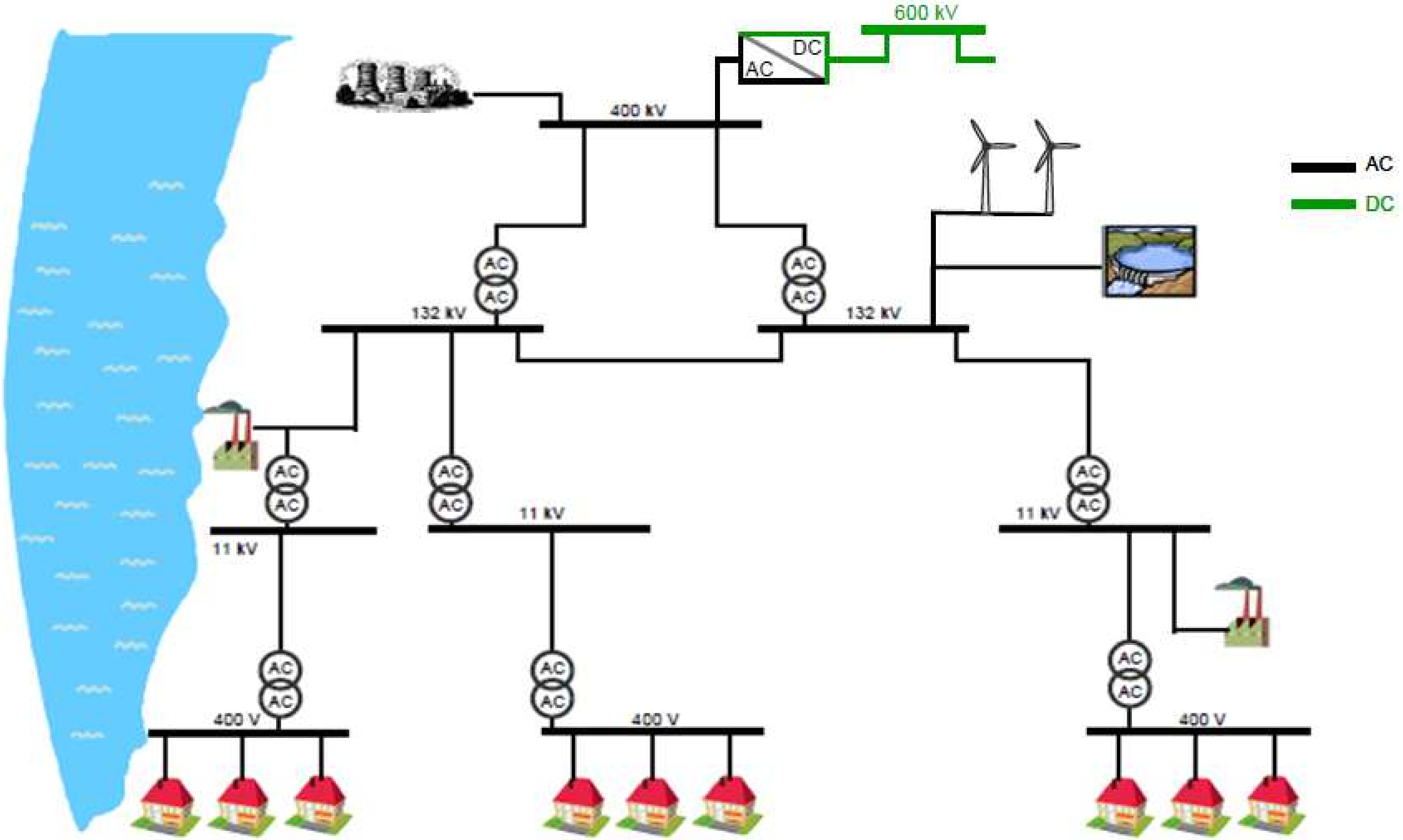
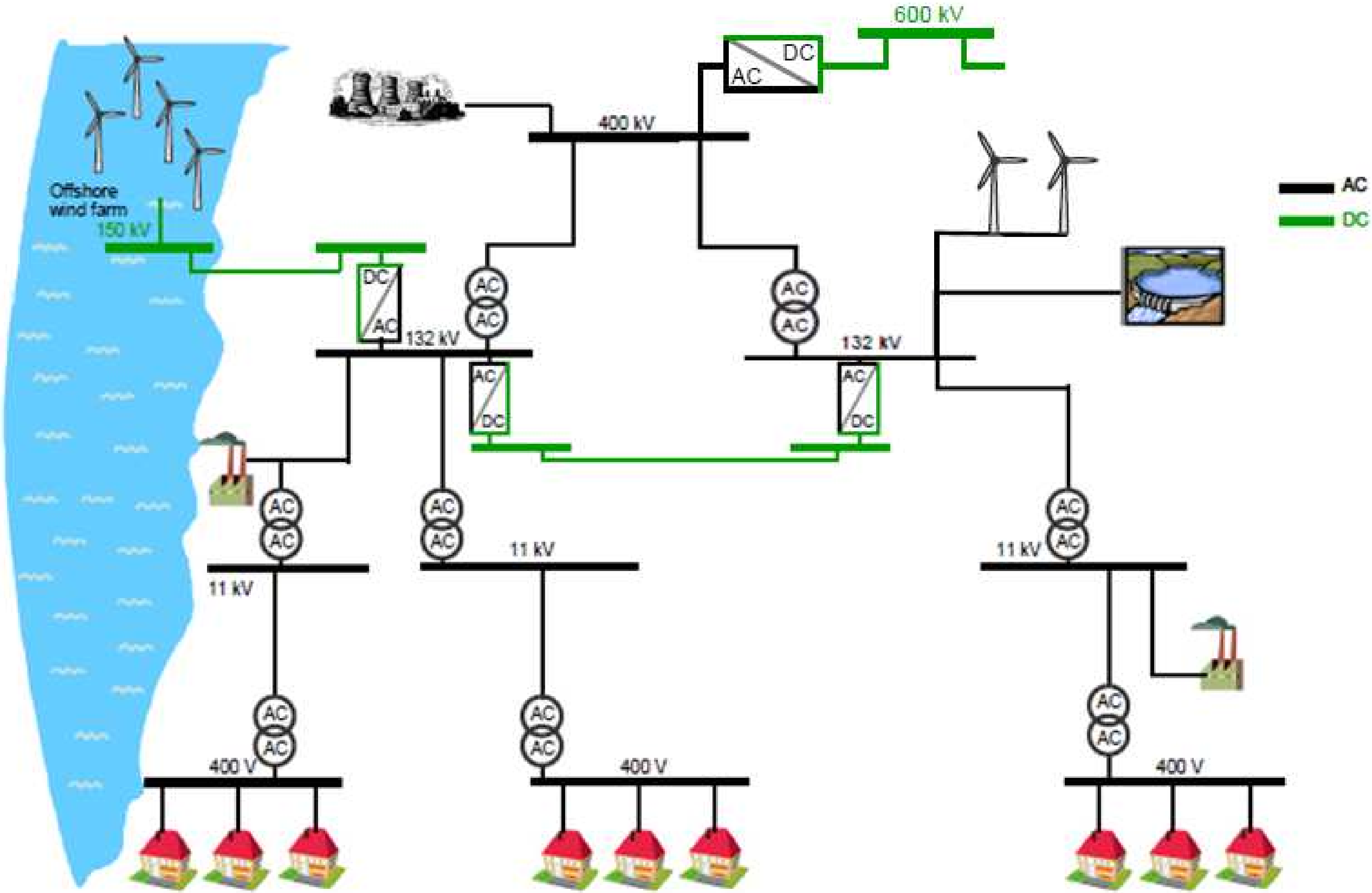


Courtesy of ALSTOM

Introduction



Courtesy of ALSTOM

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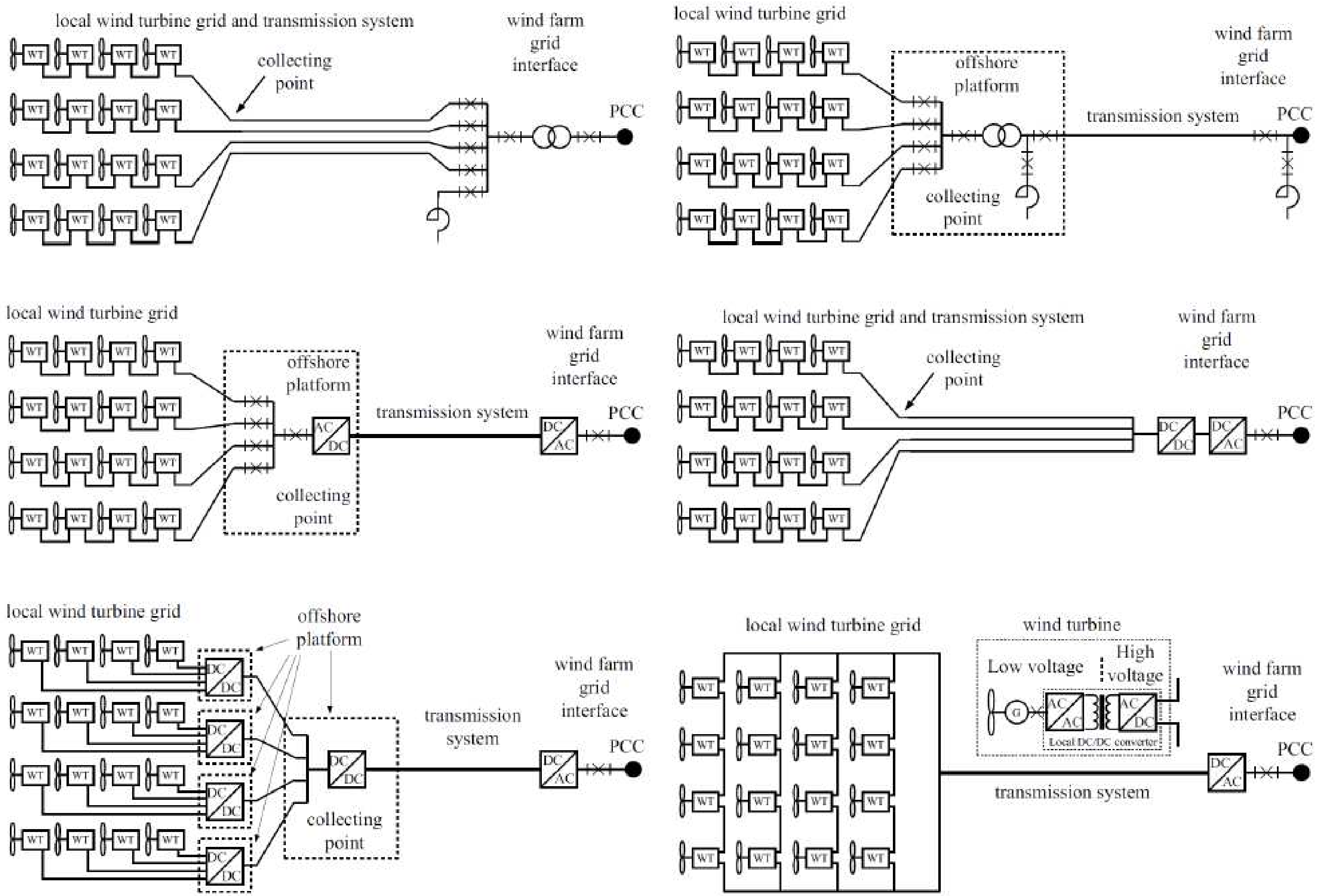
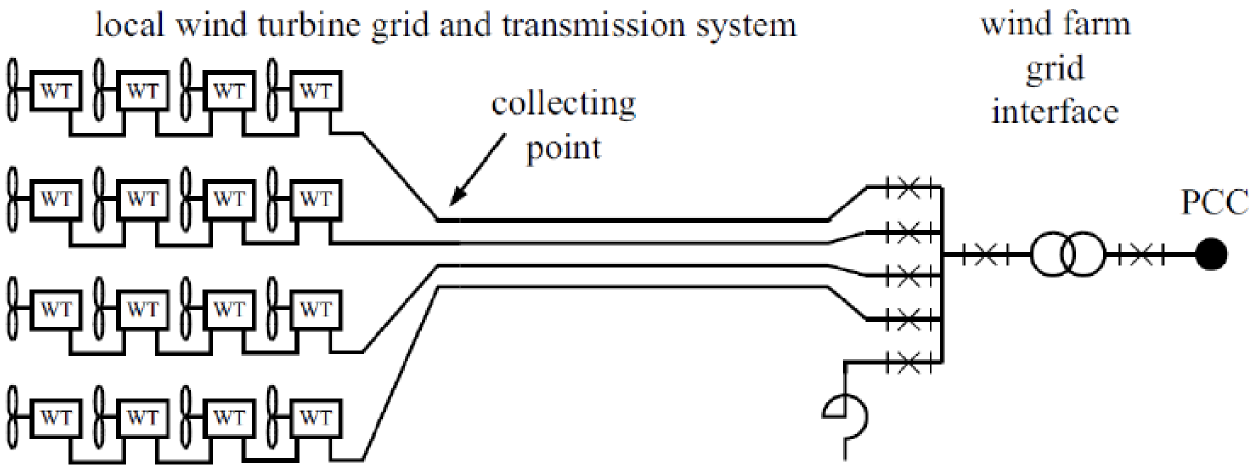


Courtesy of S. Lundberg, "Evaluation of wind farm layouts," *Proceedings of Nordic Workshop on Power and Industrial Electronics,* Trondheim, Norway: NTNU, Department of Electrical Power Engineering, June 2004.

OWPP layouts

Small AC layout

- MV AC collector system
- Collector system used to transmit the power to the Point of Common Coupling (PCC) located onshore
- No need of offshore substation
- Unfeasible for large wind farms

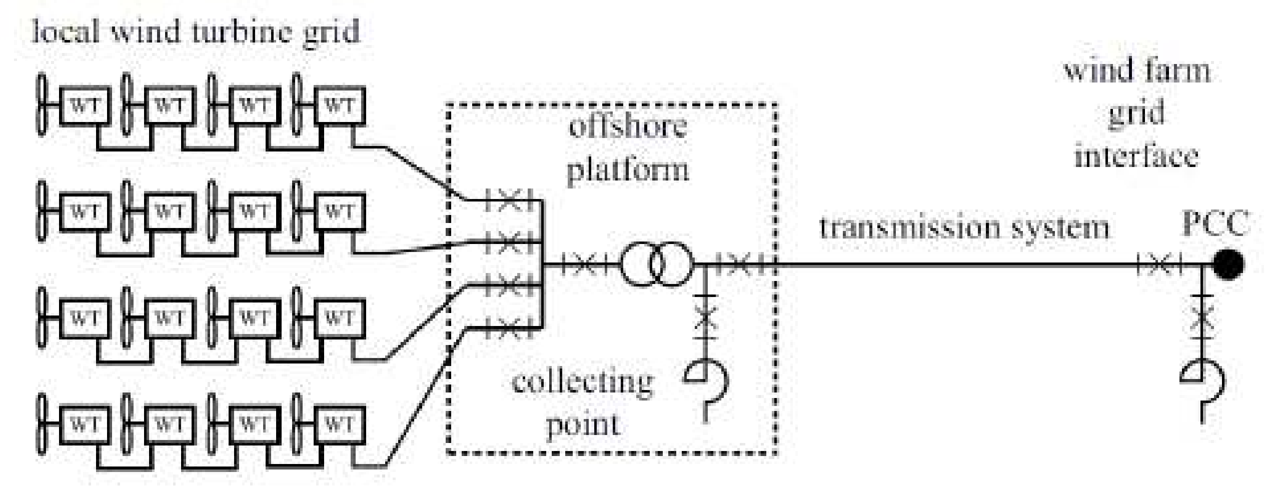


Courtesy of S. Lundberg, "Evaluation of wind farm layouts," *Proceedings of Nordic Workshop on Power and Industrial Electronics,* Trondheim, Norway: NTNU, Department of Electrical Power Engineering, June 2004.

OWPP layouts

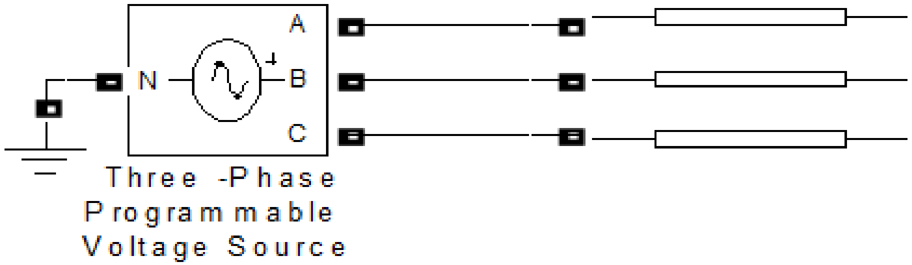
Large AC layout

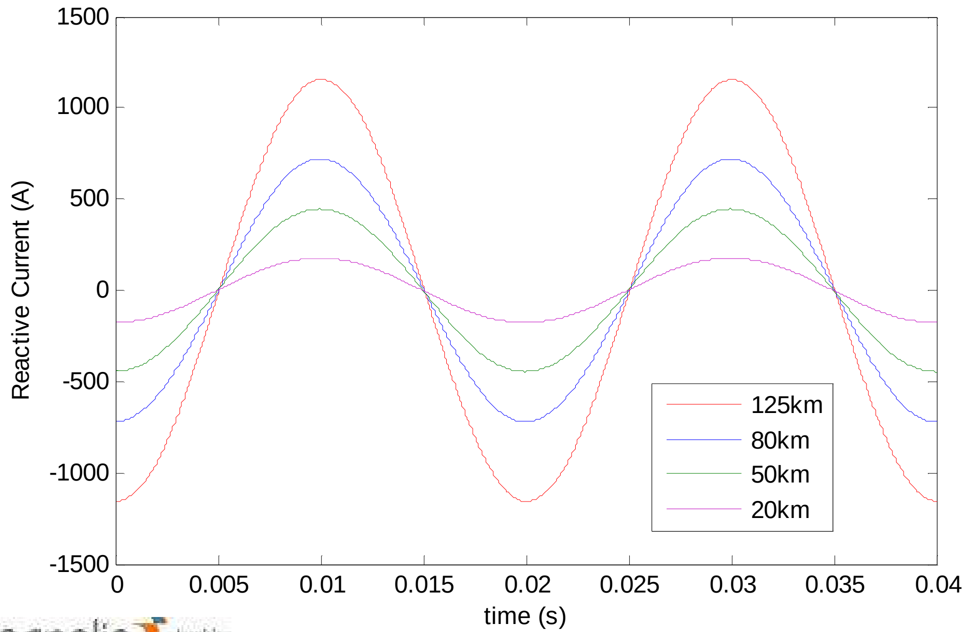
- MV AC collector system
- Offshore platform including transformer, Gas Insulated Switchgear (GIS) and reactive compensation
- HV AC transmission cable
- Onshore station



Large AC layout. Reactive energy

- Simulation of a 150 kV submarine cable with no load





The reactive current due to the parasitic cable capacitance increases with the length of the cable. This implies higher losses and a decrease in the active power transmission capacity.

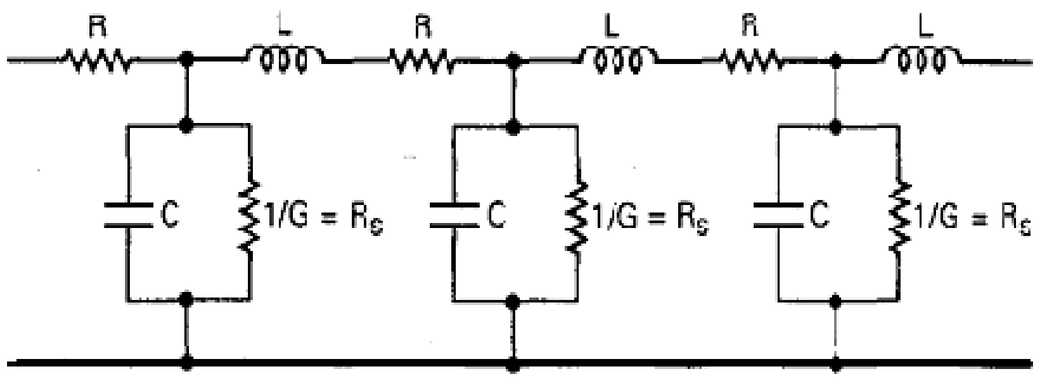
When the cable length is around 125 km the reactive current in the cable is equal to the nominal current!!! It is not possible to transmit active power.

OWPP layouts

Large AC layout. Reactive energy

- Simulation of a 150 kV submarine cable with no load

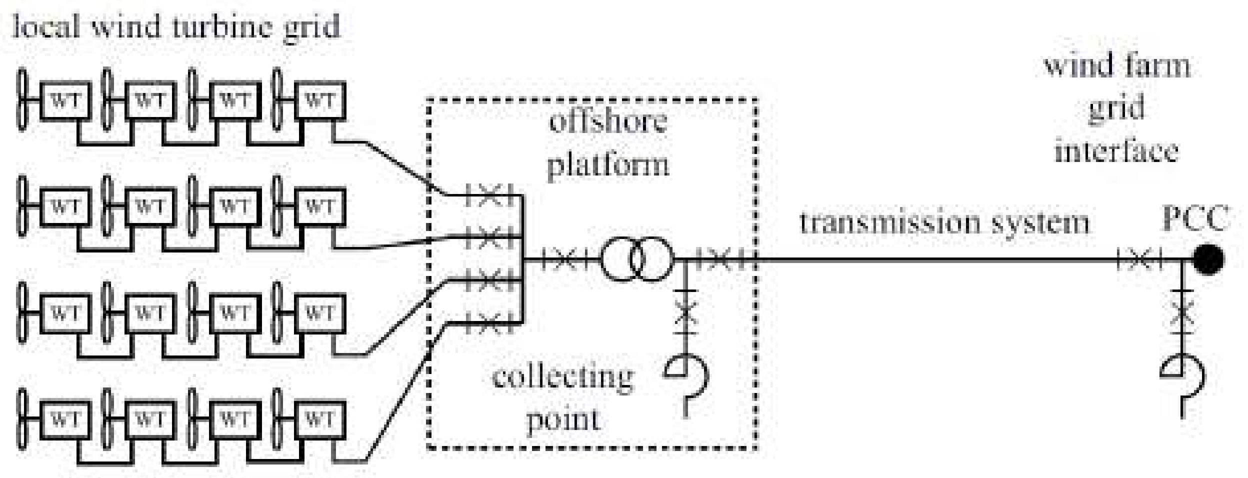
Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross section of screen	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance
mm^2	mm	mm	mm	mm^2	mm	kg/m	kg/m	μF/km	A/km	mH/km
630	29.8	17.0	66.6	2.5	194.0	57.8	69.7	0.19	5.3	0.38
800	33.7	17.0	70.5	2.7	204.0	64.7	79.8	0.21	5.7	0.37
1000	37.9	17.0	75.3	2.8	215.0	71.6	90.5	0.23	6.3	0.36



OWPP layouts

Large AC layout

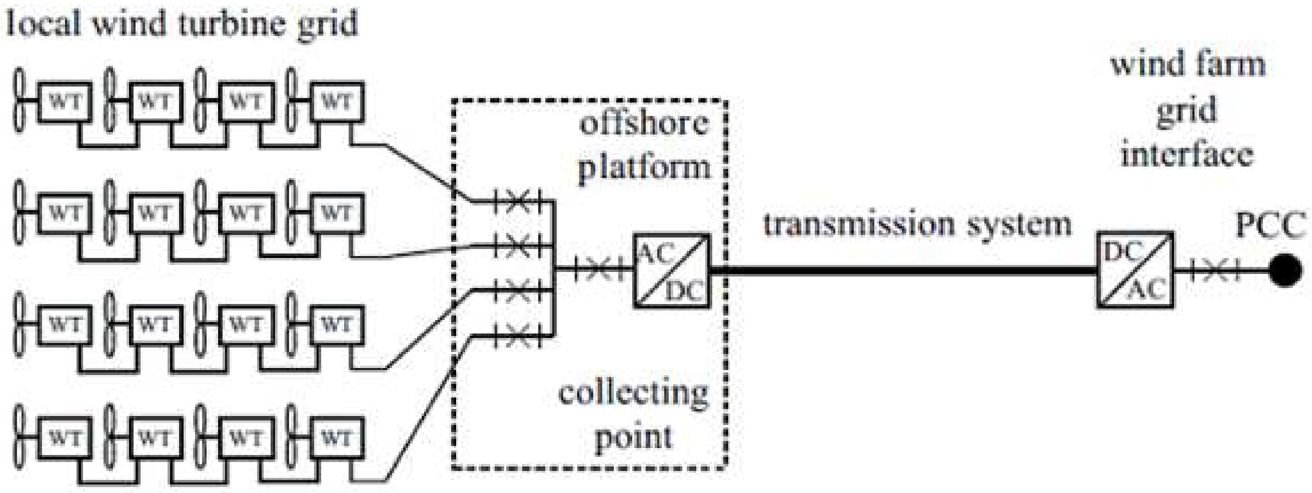
When the transmission cable is longer than 70 km aprox. the reactive current flowing in the cable due to the parasitic capacitance is high enough to reduce considerably its capacity to transmit active power. Therefore this layout is not suitable for those offshore wind farm located far from the PCC.



OWPP layouts

HVDC layout

- MV AC collector system
- Offshore platform including AC/DC converters
- DC transmission cable
- Onshore station with DC/AC converters



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HVDC-VSC technology overview

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- Modular multilevel converters

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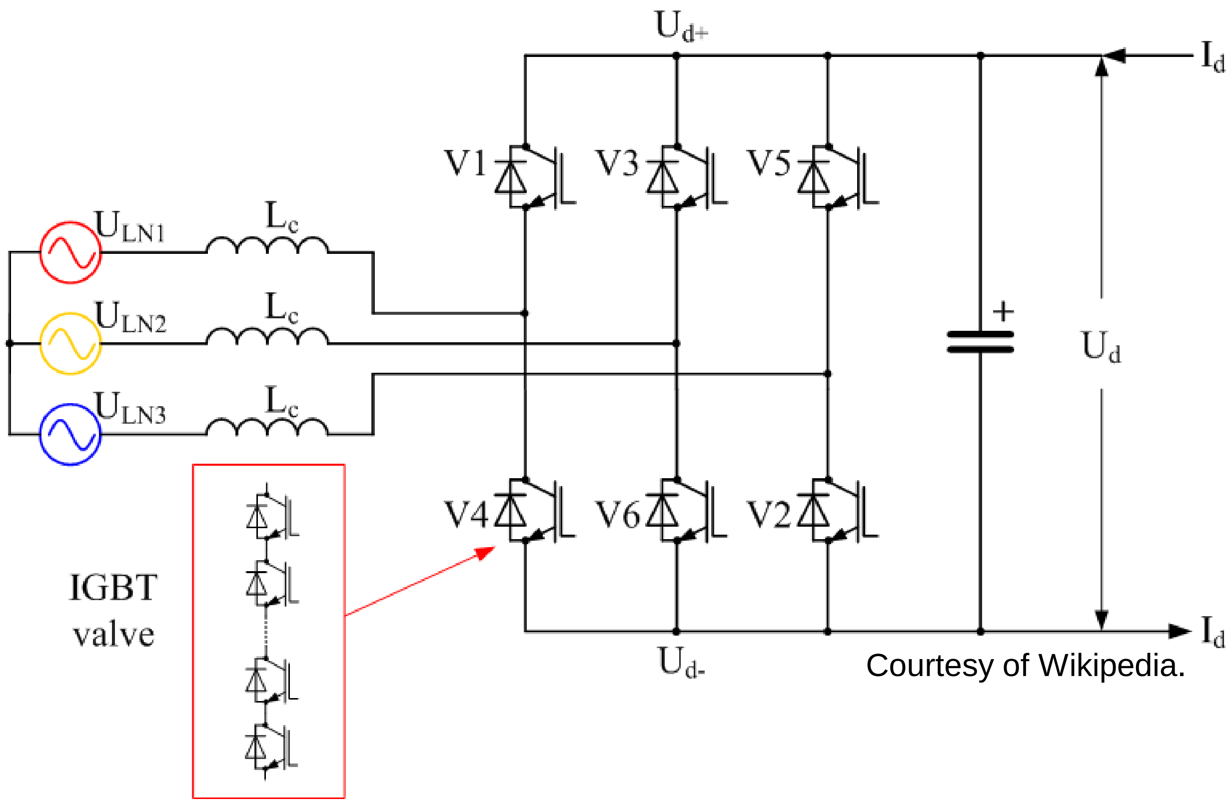
HVDC-VSC technology overview

Two level converters with series connected IGBTs

- ABB late 90s, Siemens 2000-2003



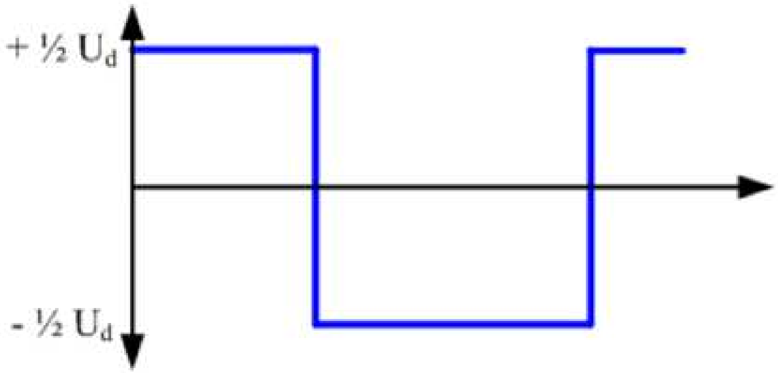
Courtesy of Wikipedia.

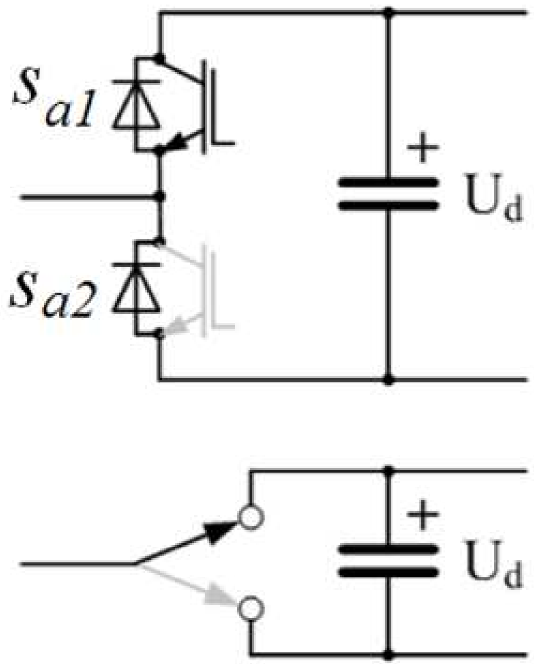
HVDC-VSC technology overview

Two level converters with series connected IGBTs

- Switching states

***Sa1* ON *Sa2* OFF→$v=v_{a0}$=Vdc/2**





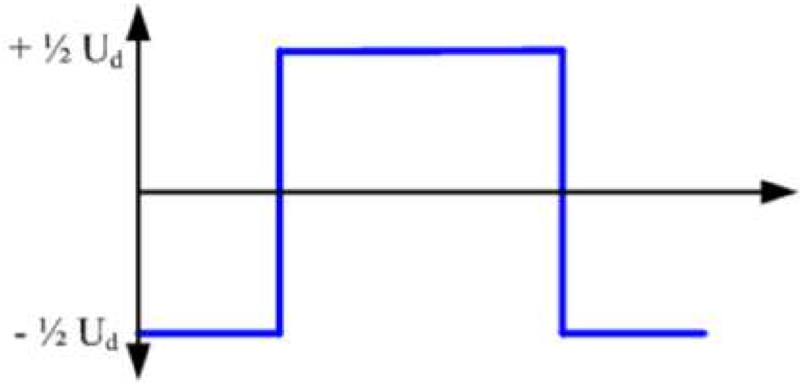
HVDC-VSC technology overview

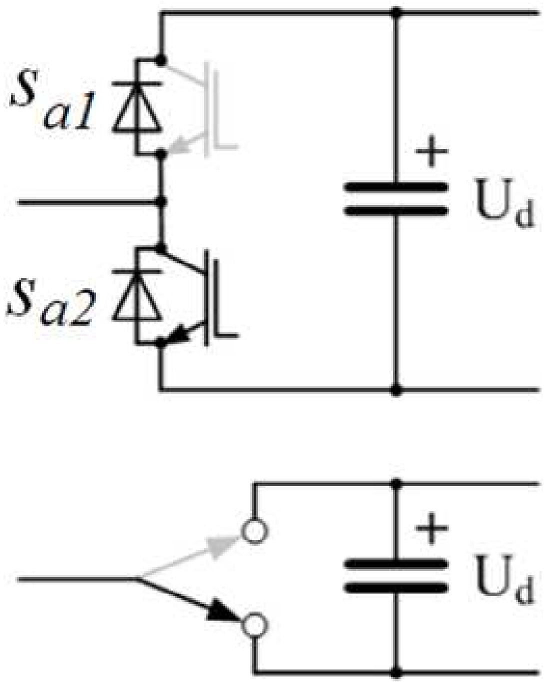
Two level converters with series connected IGBTs

- Switching states

Sa1 ON *Sa2* OFF→$v=v_{a0}$=Vdc/2

***Sa1* OFF *Sa2* ON→*v=va0*=-Vdc/2**





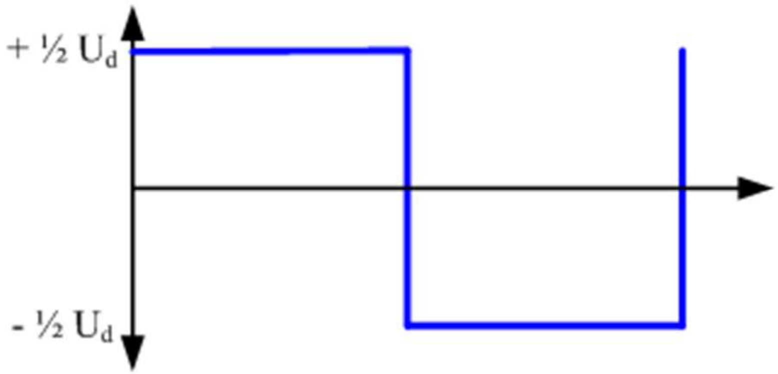
HVDC-VSC technology overview

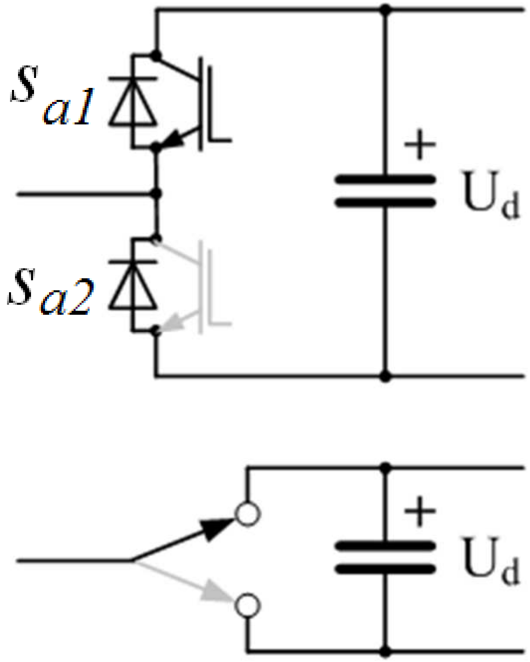
Two level converters with series connected IGBTs

- **Switching states**

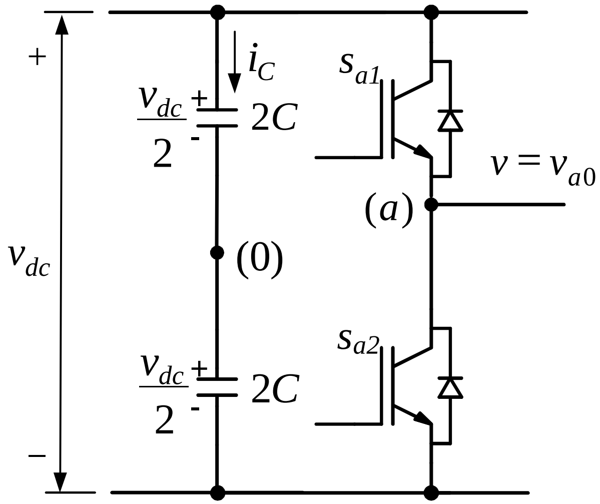
***Sa1* ON *Sa2* OFF→$v=v_{a0}$=Vdc/2**

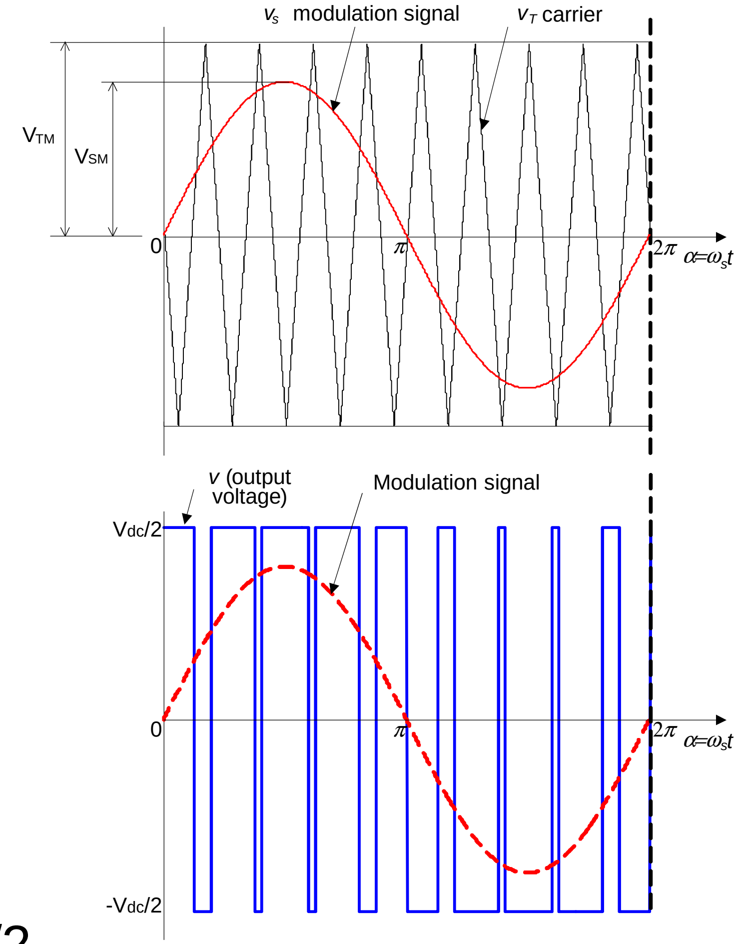
***Sa1* OFF *Sa2* ON→*v=va0*=-Vdc/2**





Two level converters with series connected IGBTs. PWM modulation





Modulation signal:

$v_s(t)=V_{SM}\sin\omega_s t$

Output voltage:

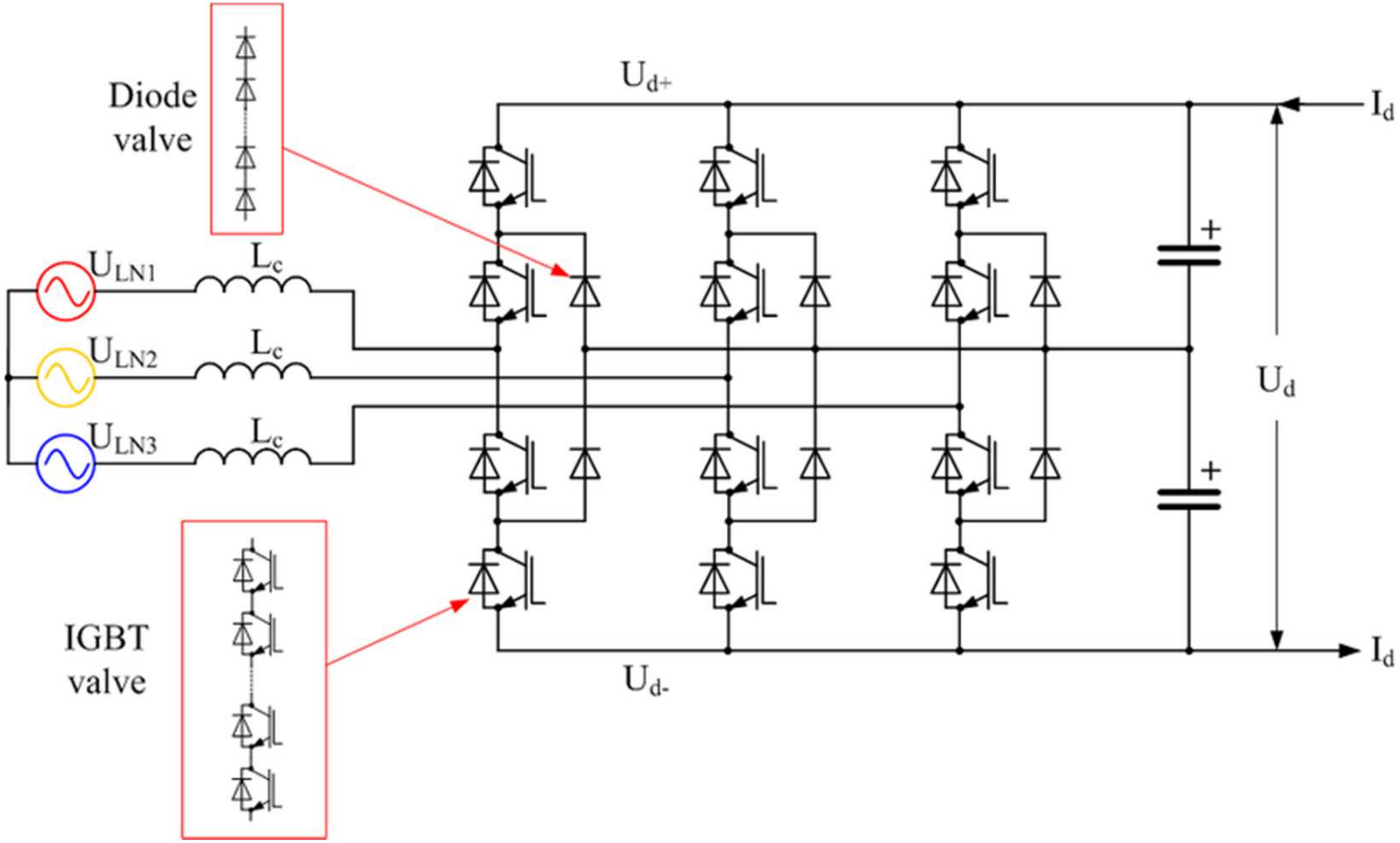
If $v_s \geq v_T \rightarrow$ *Sa1* ON *Sa2* OFF$\rightarrow v=v_{a0}$=Vdc/2

If $v_s < v_T \rightarrow$ *Sa1* OFF *Sa2* ON$\rightarrow$*v=va0*=-Vdc/2

HVDC-VSC technology overview

Three level NPC converters with series connected IGBTs

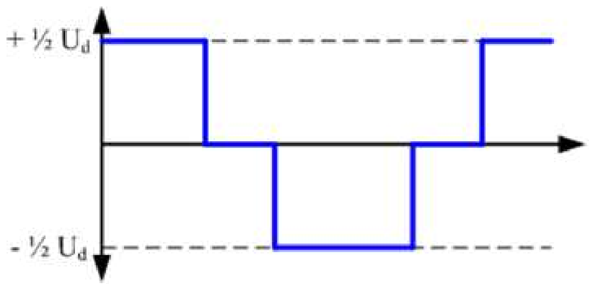
- ABB 2000-2005

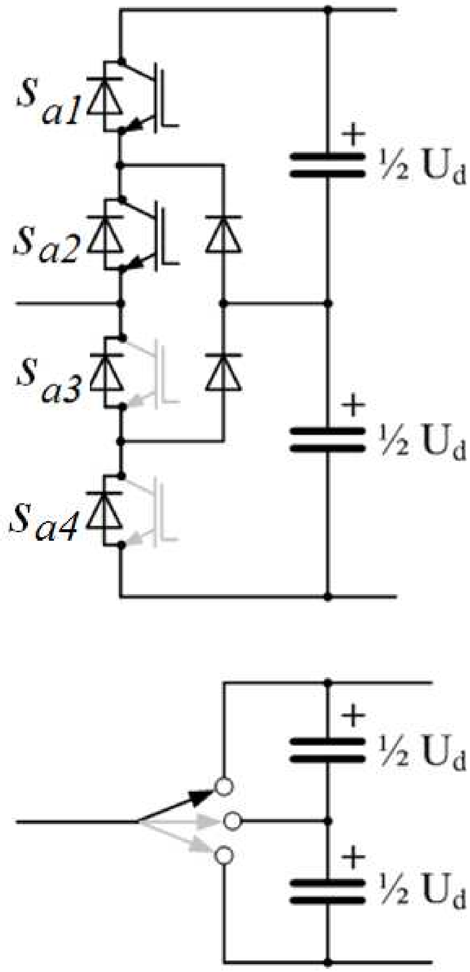


Three level NPC converters with series connected IGBTs

- Switching states

***Sa1* ON *Sa2* ON *Sa3* OFF *Sa4* OFF** $\rightarrow v_{a0}$**=Udc/2**



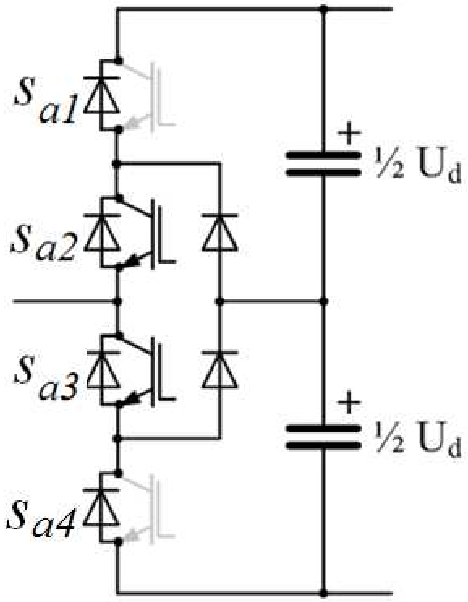


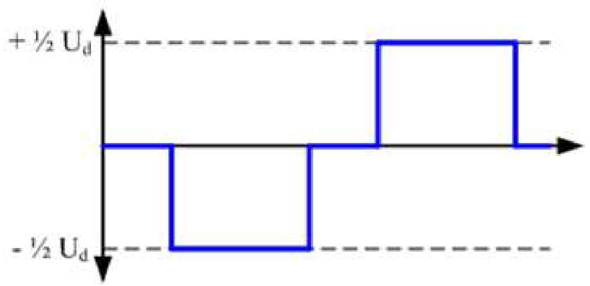
Three level NPC converters with series connected IGBTs

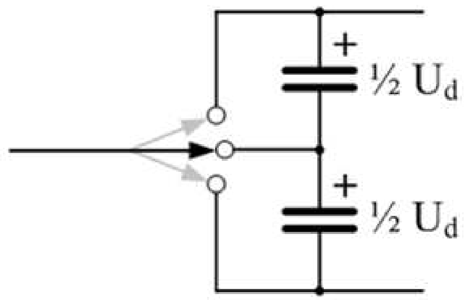
- Switching states

Sa1 ON *Sa2* ON *Sa3* OFF *Sa4* OFF $\rightarrow v_{a0}$=Udc/2

***Sa1* OFF *Sa2* ON *Sa3* ON *Sa4* OFF $\rightarrow v_{a0}$=0**







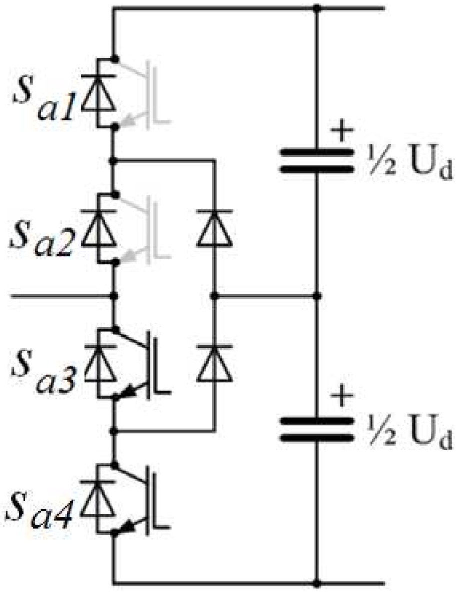
Three level NPC converters with series connected IGBTs

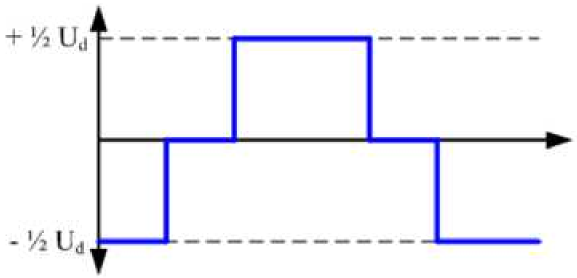
- Switching states

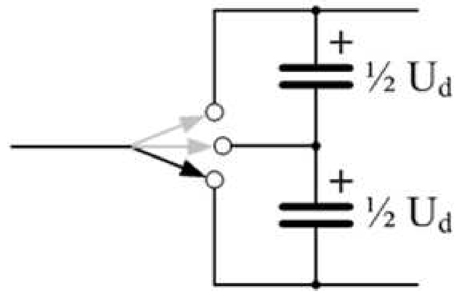
Sa1 ON *Sa2* ON *Sa3* OFF *Sa4* OFF →v_{a0}=Udc/2

Sa1 OFF *Sa2* ON *Sa3* ON *Sa4* OFF →v_{a0}=0

_Sa1_ OFF _Sa2_ OFF _Sa3_ ON _Sa4_ ON →v_{a0}=-Udc/2







HVDC-VSC technology overview

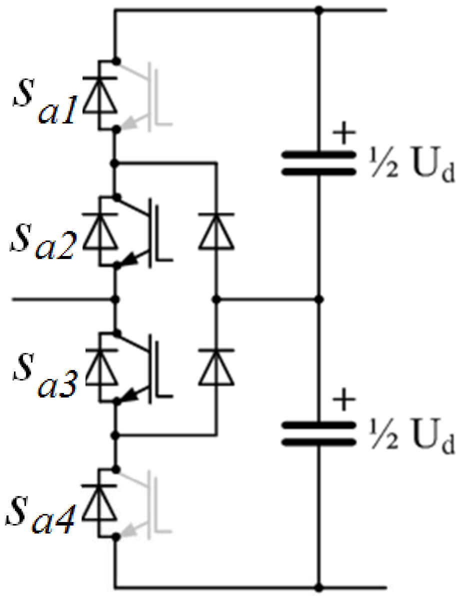
Three level NPC converters with series connected IGBTs

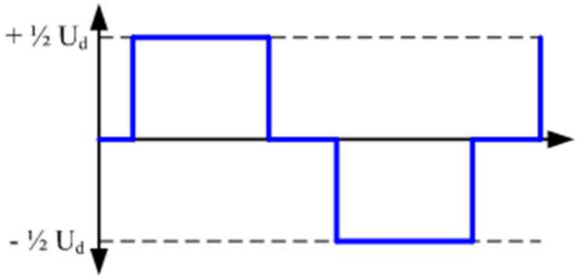
- Switching states

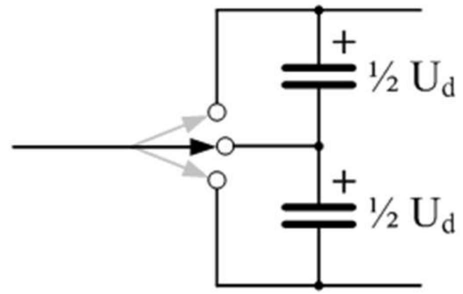
Sa1 ON *Sa2* ON *Sa3* OFF *Sa4* OFF →v_{a0}=Udc/2

Sa1 OFF *Sa2* ON *Sa3* ON *Sa4* OFF →v_{a0}=0

Sa1 OFF *Sa2* OFF *Sa3* ON *Sa4* ON →v_{a0}=-Udc/2







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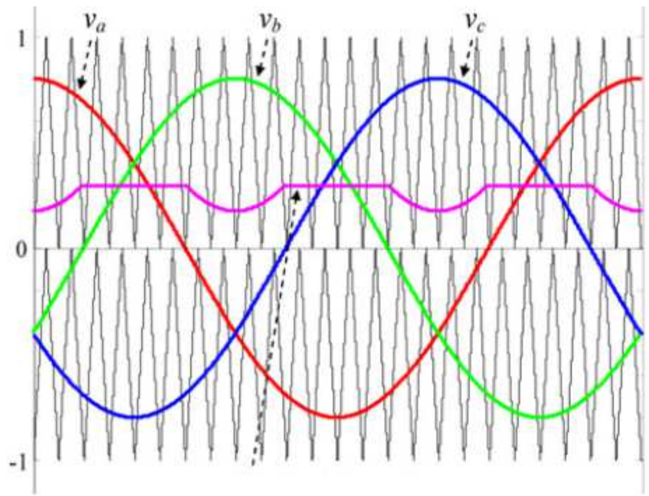
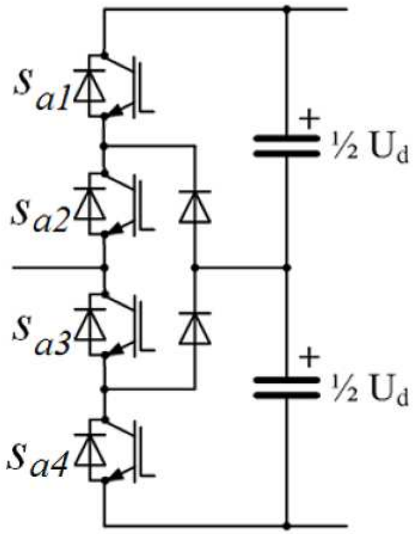
HVDC-VSC technology overview

- **Three level NPC converters with series connected IGBTs. PWM modulation.**





Modulation signal

$v_s(t)=V_{SM}\sin\omega_s t$

Ouput voltage

if $v_s \geq 0$ *and* $v_s \geq v_{T1}$ $\rightarrow$ *Sa1* ON *Sa2* ON *Sa3* OFF *Sa3* OFF $\rightarrow v=v_{a0}$=Ud/2

if $v_s \geq 0$ *and* $v_s < v_{T1}$ $\rightarrow$ *Sa1* OFF *Sa2* ON *Sa3* ON *Sa3* OFF $\rightarrow v=v_{a0}$=0

if $v_s < 0$ *and* $v_s \geq v_{T2}$ $\rightarrow$ *Sa1* OFF *Sa2* ON *Sa3* ON *Sa3* OFF $\rightarrow v=v_{a0}$=0

if $v_s < 0$ *and* $v_s < v_{T2}$ $\rightarrow$ *Sa1* OFF *Sa2* OFF *Sa3* ON *Sa3* ON $\rightarrow v=v_{a0}$=-Udc/2

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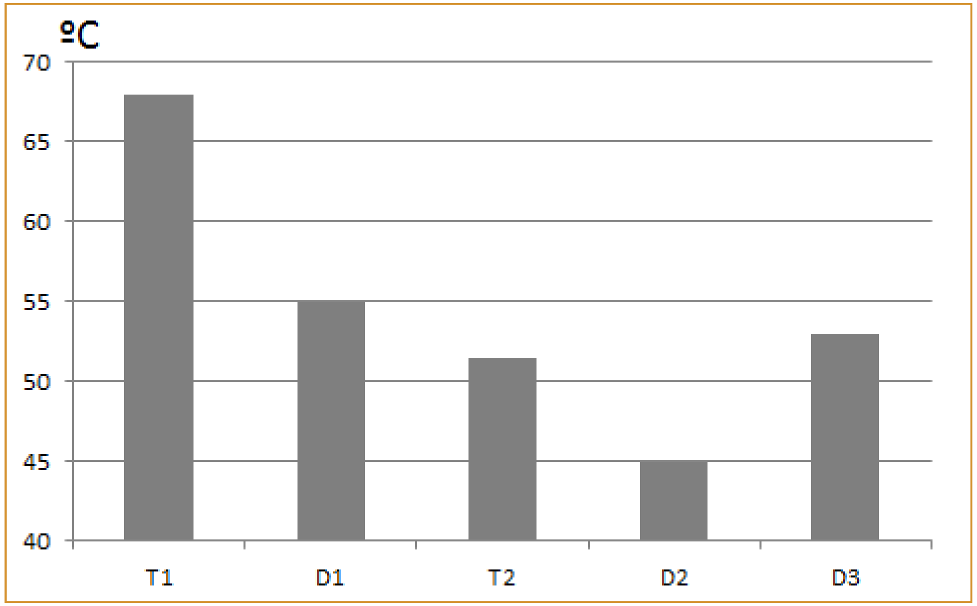
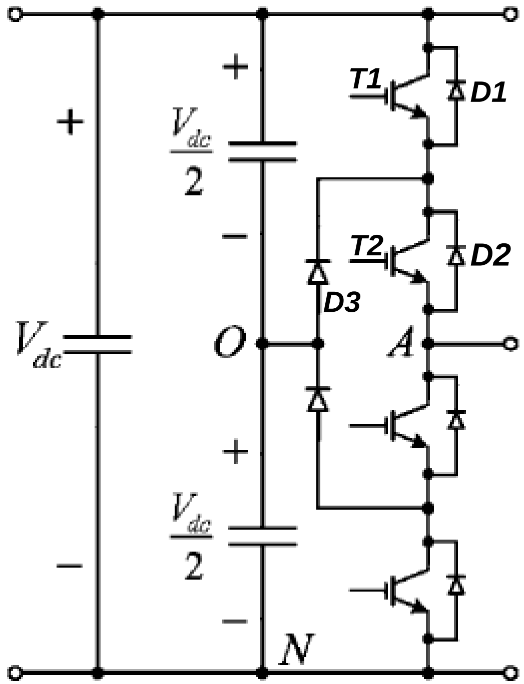
HVDC-VSC technology overview

Three level NPC converters with series connected IGBTs

- Loss distribution

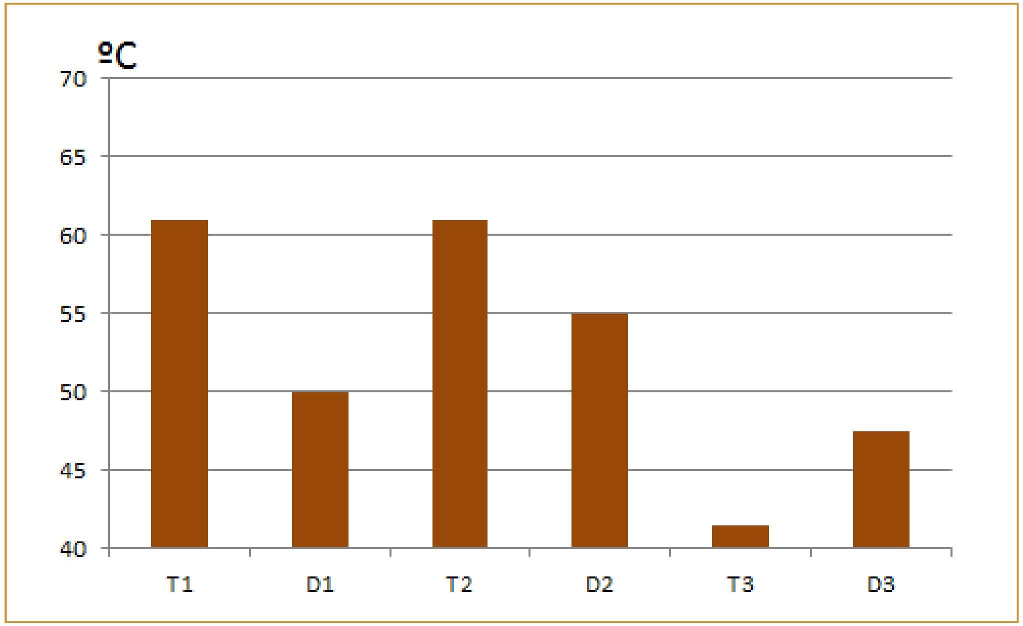


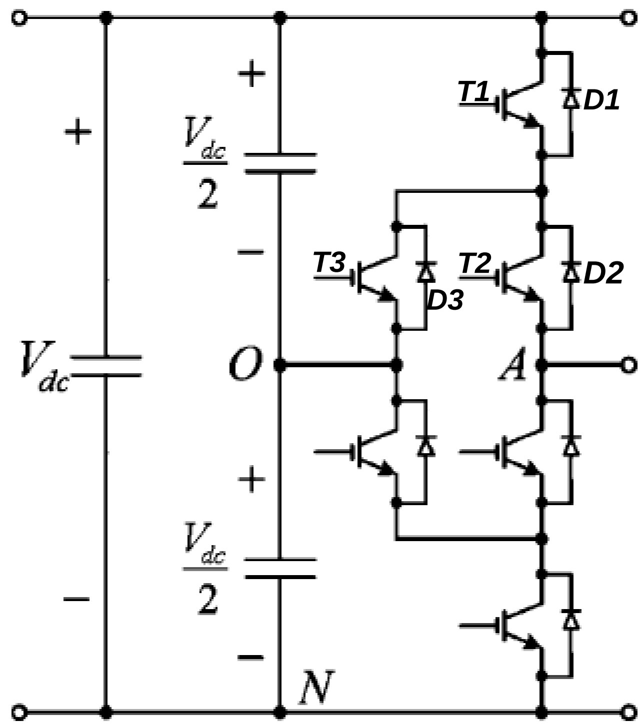


Uneven loss distribution between the switching devices. The converter needs to be overrated.

HVDC-VSC technology overview

- **Three level Active NPC (ANPC) converters with series connected IGBTs**





The ANPC introduces additional switching states that can be used to balance the power losses between semiconductor devices. Better converter use is achieved.

HVDC-VSC technology overview

- Two and three level converters can facilitate AC/DC conversion in HVDC applications. However:
  - High switching frequency is mandatory due to the reduced number of levels .
  - Poor efficiency.
  - Direct connection of switching devices required.
  - Not easy scalable to higher power/voltage levels.

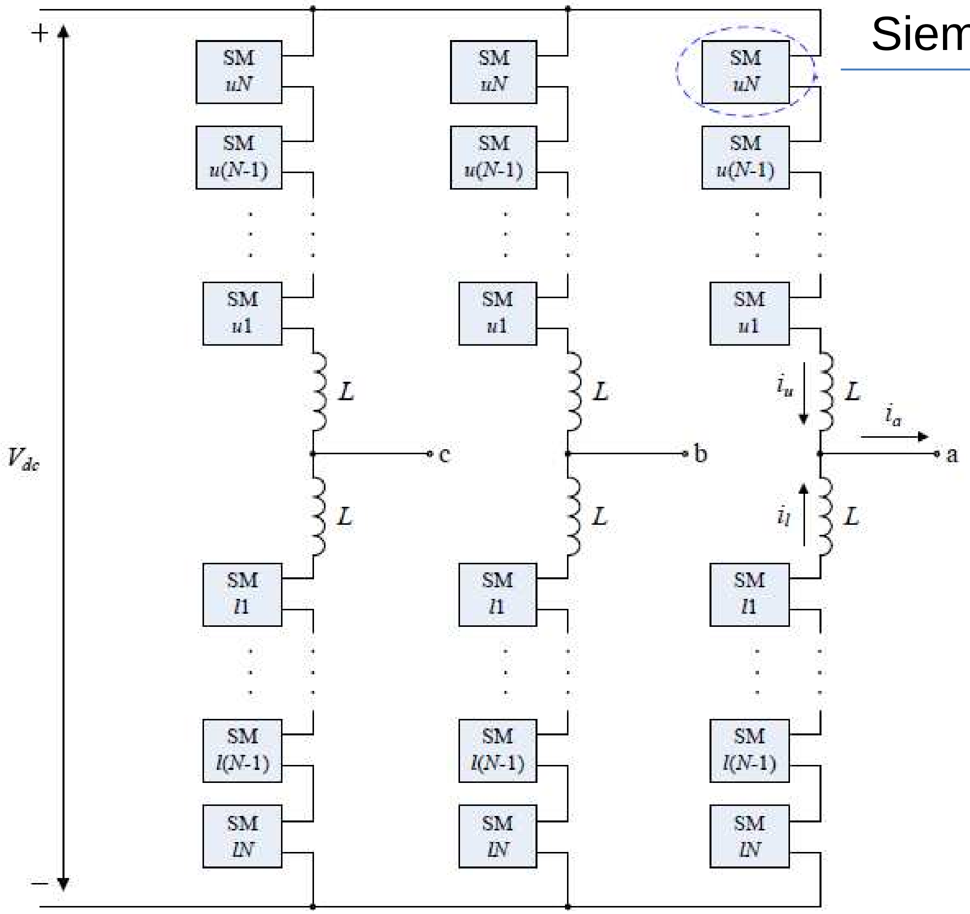
↓

Modular Multilevel Converters MMC

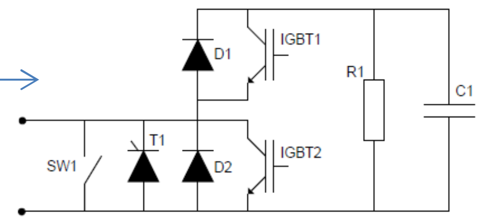
HVDC-VSC technology overview

Modular multilevel converters: Topology and manufacturers implementation

- Siemens 2007, ABB 2010, Alstom 2010



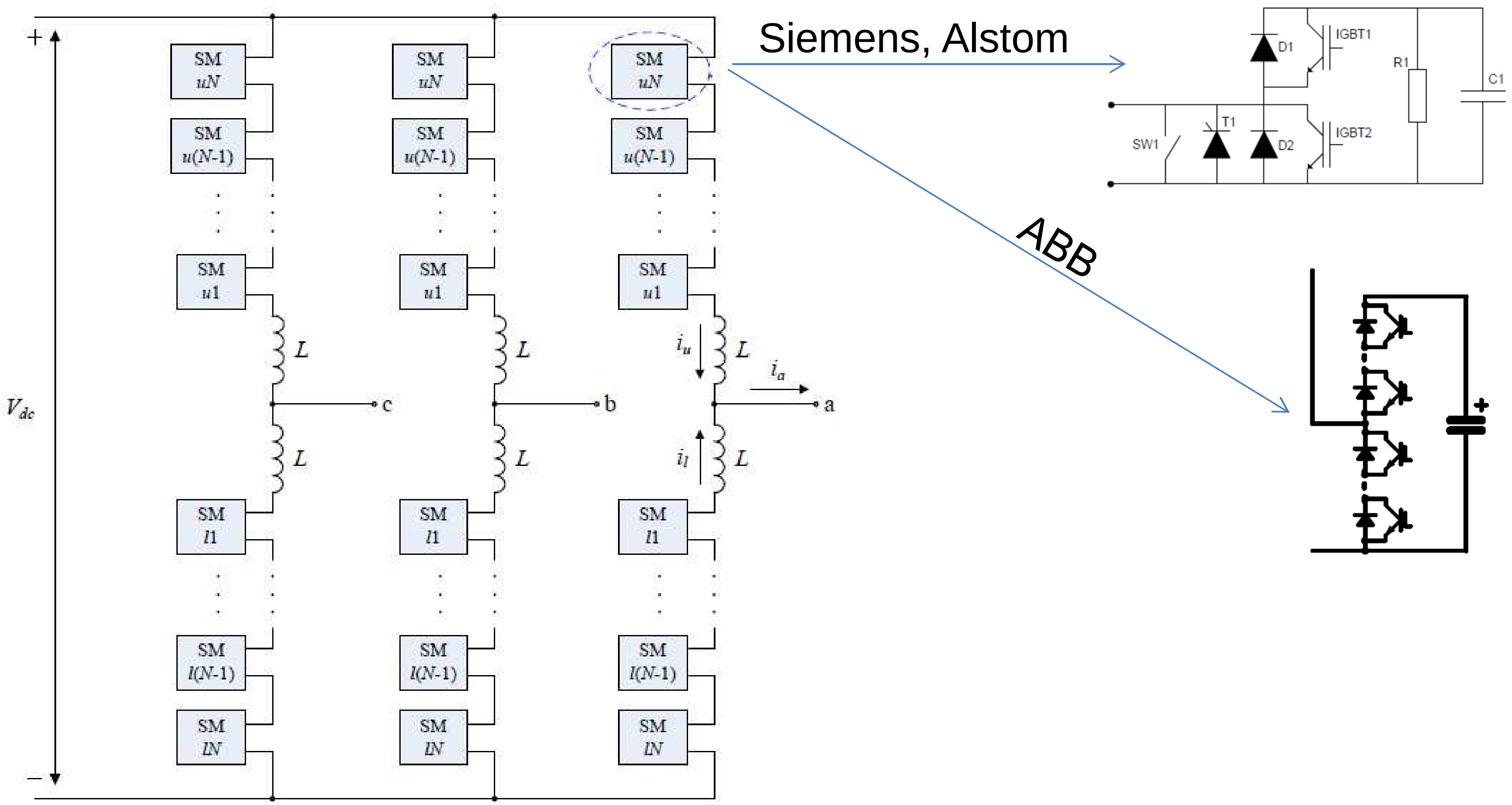
Siemens, Alstom



HVDC-VSC technology overview

Modular multilevel converters: Topology and manufacturers implementation

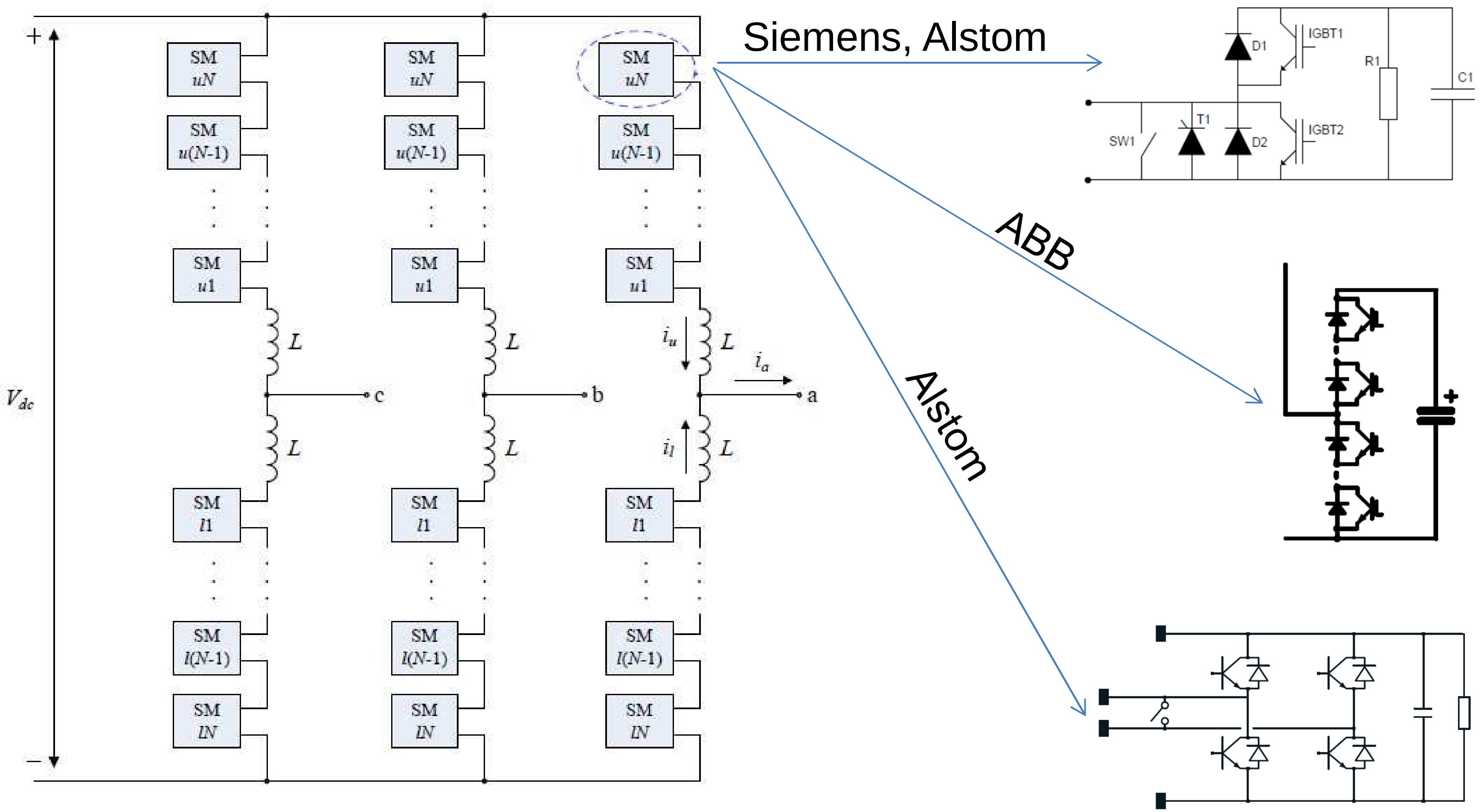
- Siemens 2007, ABB 2010, Alstom 2010



HVDC-VSC technology overview

Modular multilevel converters: Topology and manufacturers implementation

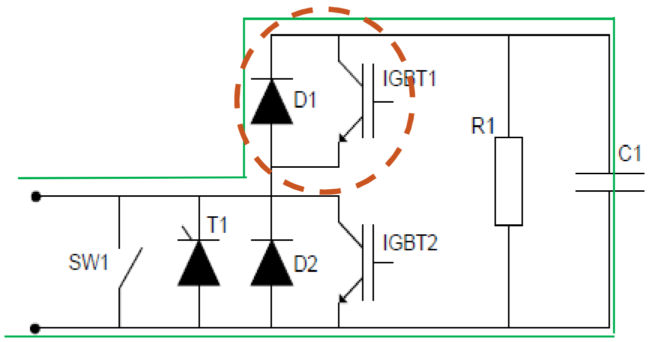
- Siemens 2007, ABB 2010, Alstom 2010



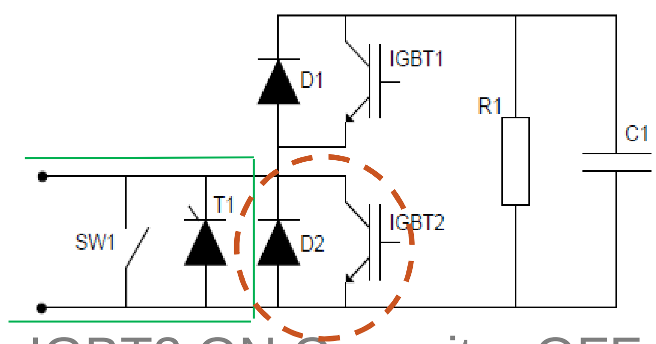
Figures courtesy of ALSTOM

HVDC-VSC technology overview

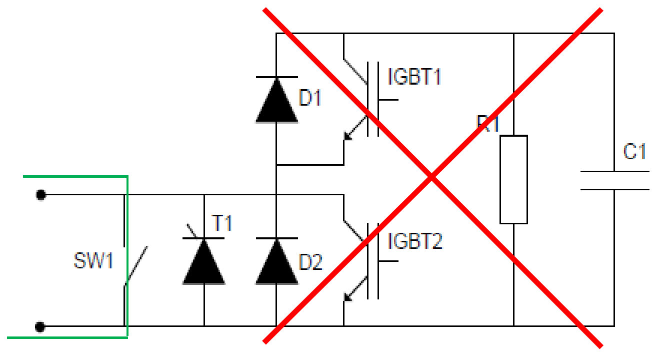
Modular multilevel converters: Switching states



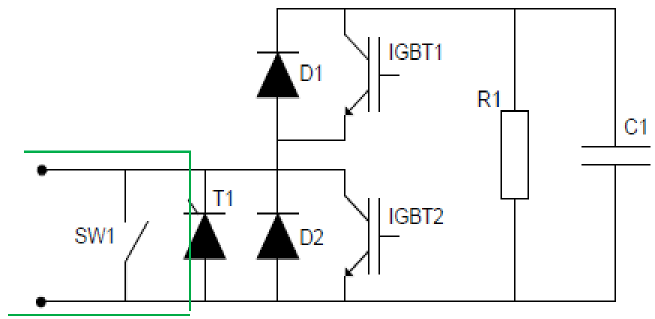
IGBT1 ON Capacitor ON



IGBT2 ON Capacitor OFF



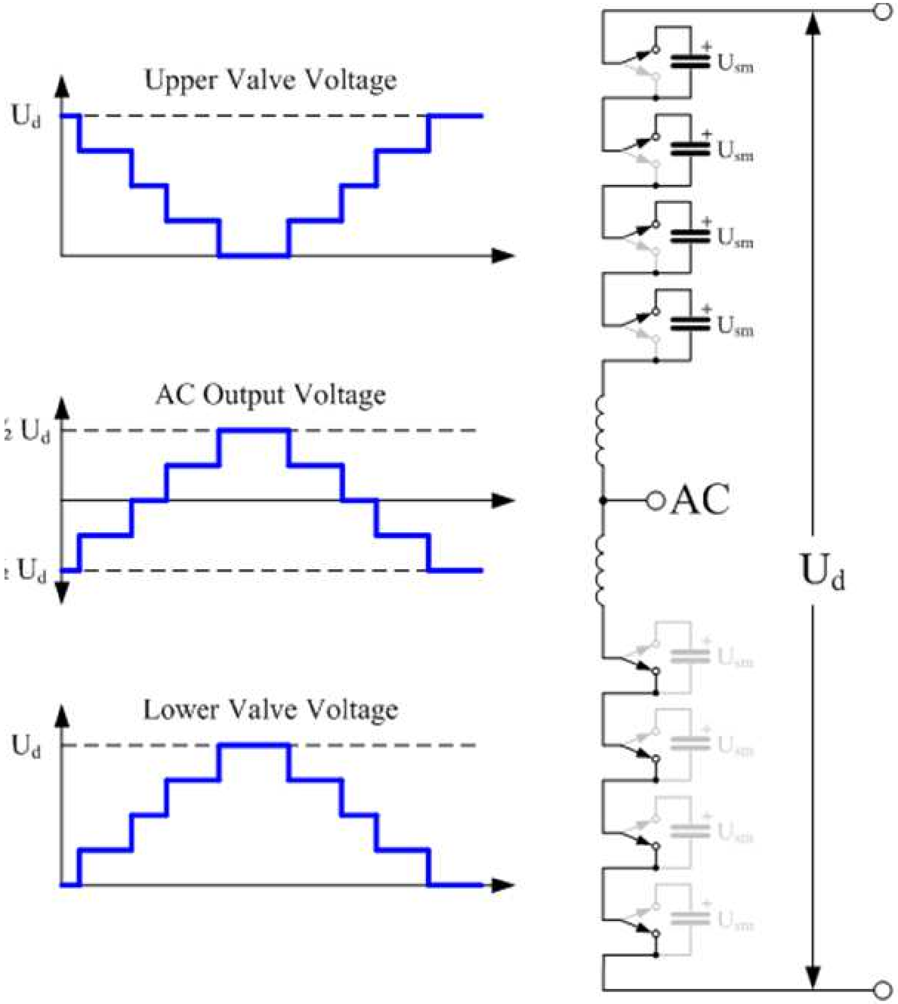
Submodule failure SW1 ON



DC short-circuit T1 ON

HVDC-VSC technology overview

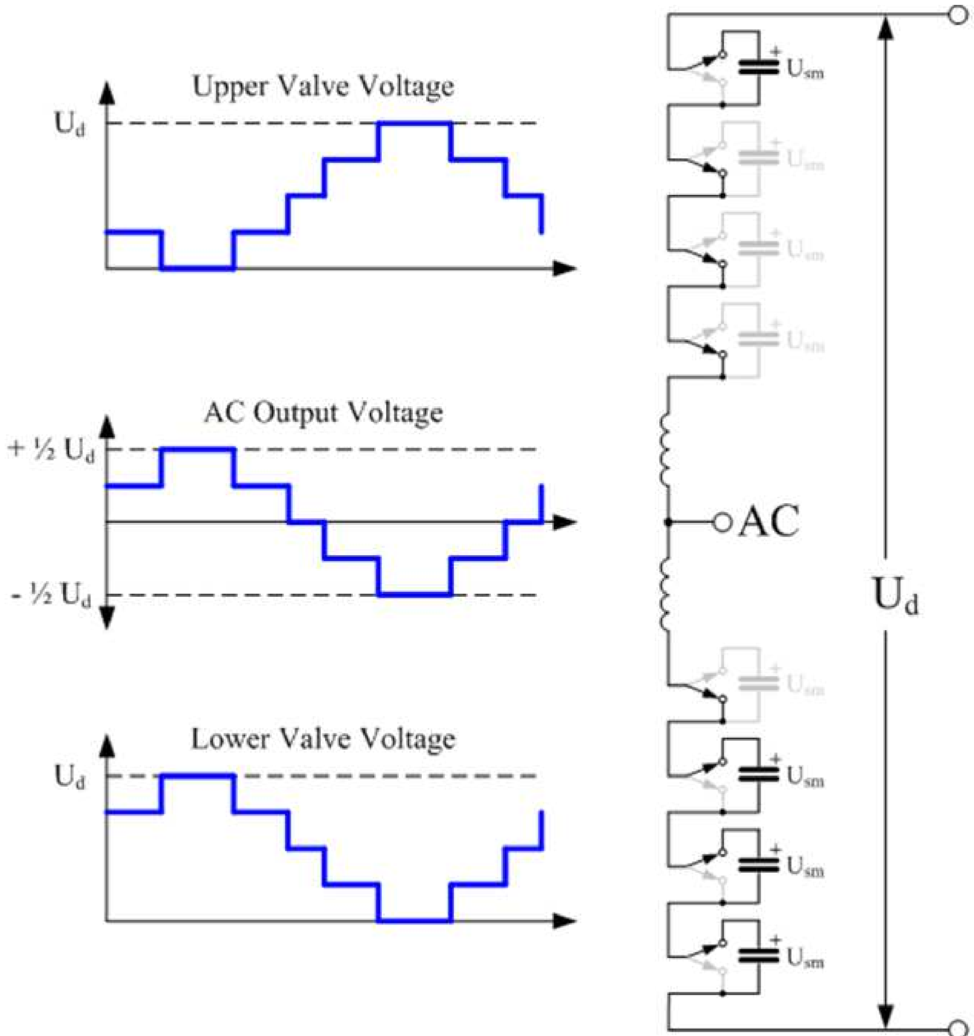
Modular multilevel converters: Switching states and commutation rules



- The number of activated submodules should be equal to *n*, being *n* the number of submodules in an arm.

HVDC-VSC technology overview

Modular multilevel converters: Switching states and commutation rules



- The number of activated submodules should be equal to *n*, being *n* the number of submodules in an arm.

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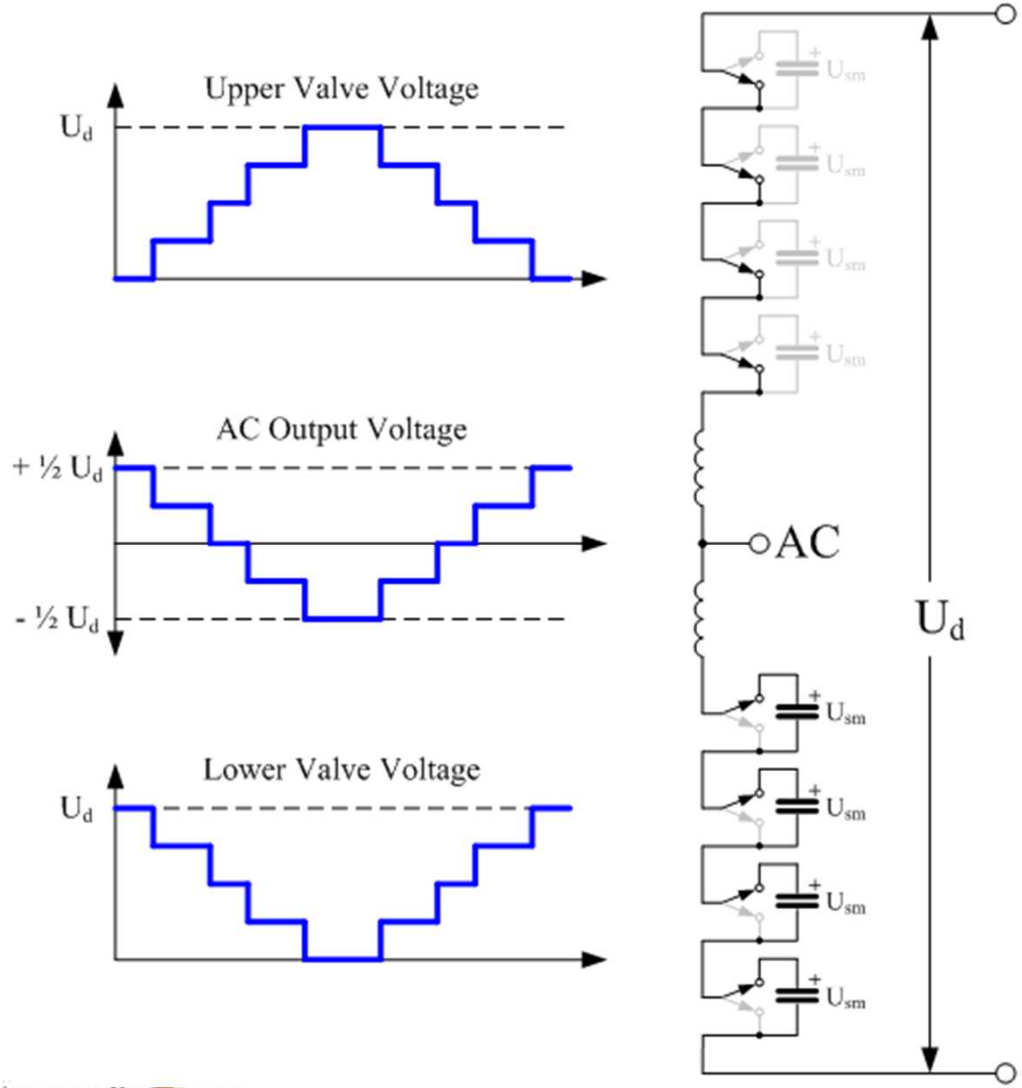
HVDC-VSC technology overview

Modular multilevel converters: Switching states and commutation rules



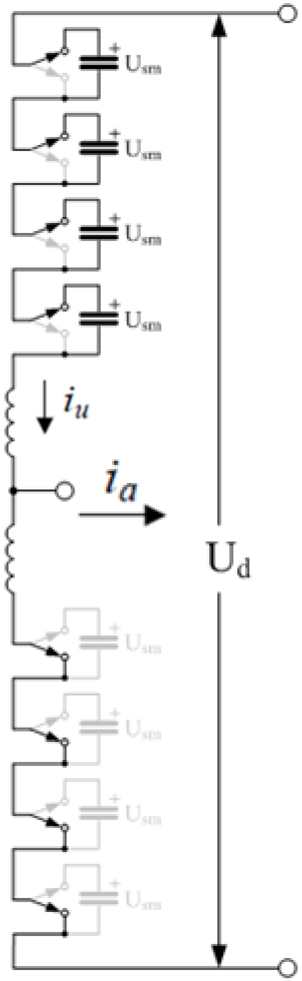
Advantages:

- Low switching frequency
- High efficiency (around 99%)
- Easily scalable
- Low harmonic distortion

Disadvantages:

- Requires twice the number of semiconductors than a two level converter and heavier capacitors.
- Complex control

Modular multilevel converters: Equivalent circuit



To maintain the charge in the capacitors stable a dc current has to be added to the arm currents.

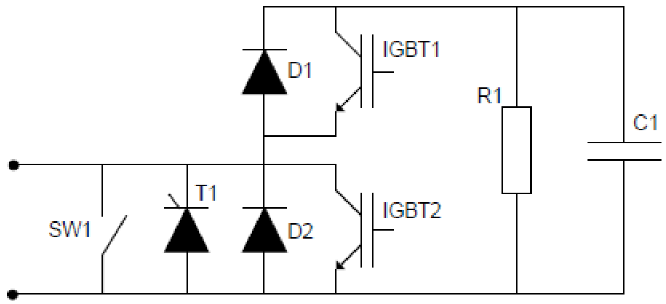
$$i_u = \frac{i_a}{2} + i_{dc}$$

It can be demonstrated that the dc current needed to maintain stable the capacitors voltage is given by the following expression:

$$i_{dc} = \frac{v_{ac} i_a \cos \emptyset}{2U_d}$$

HVDC-VSC technology overview

- **Modular multilevel converters: Manufacturers implementations**



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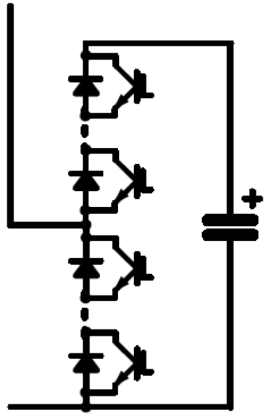
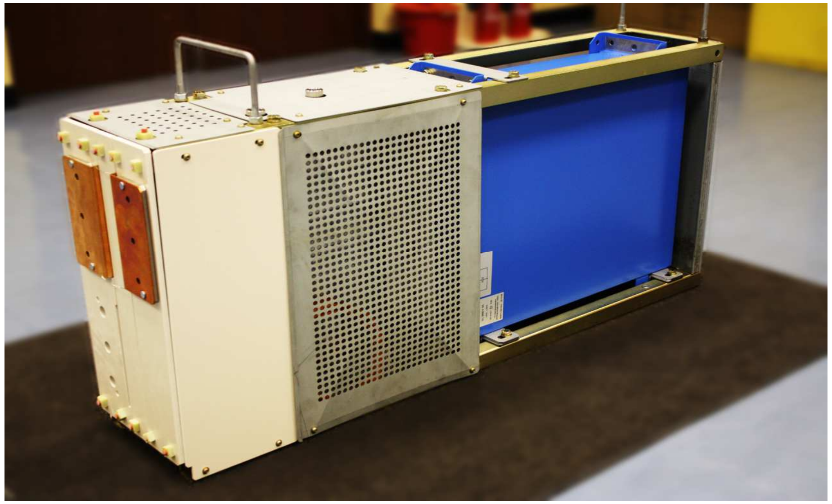
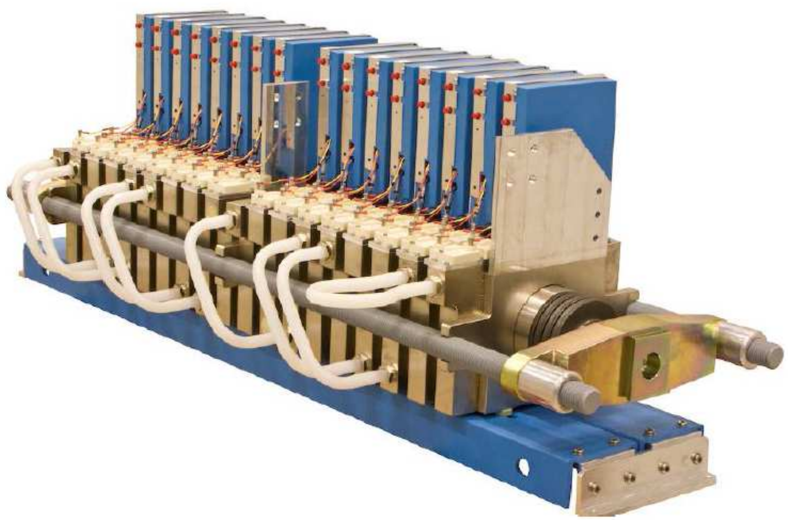


ABB

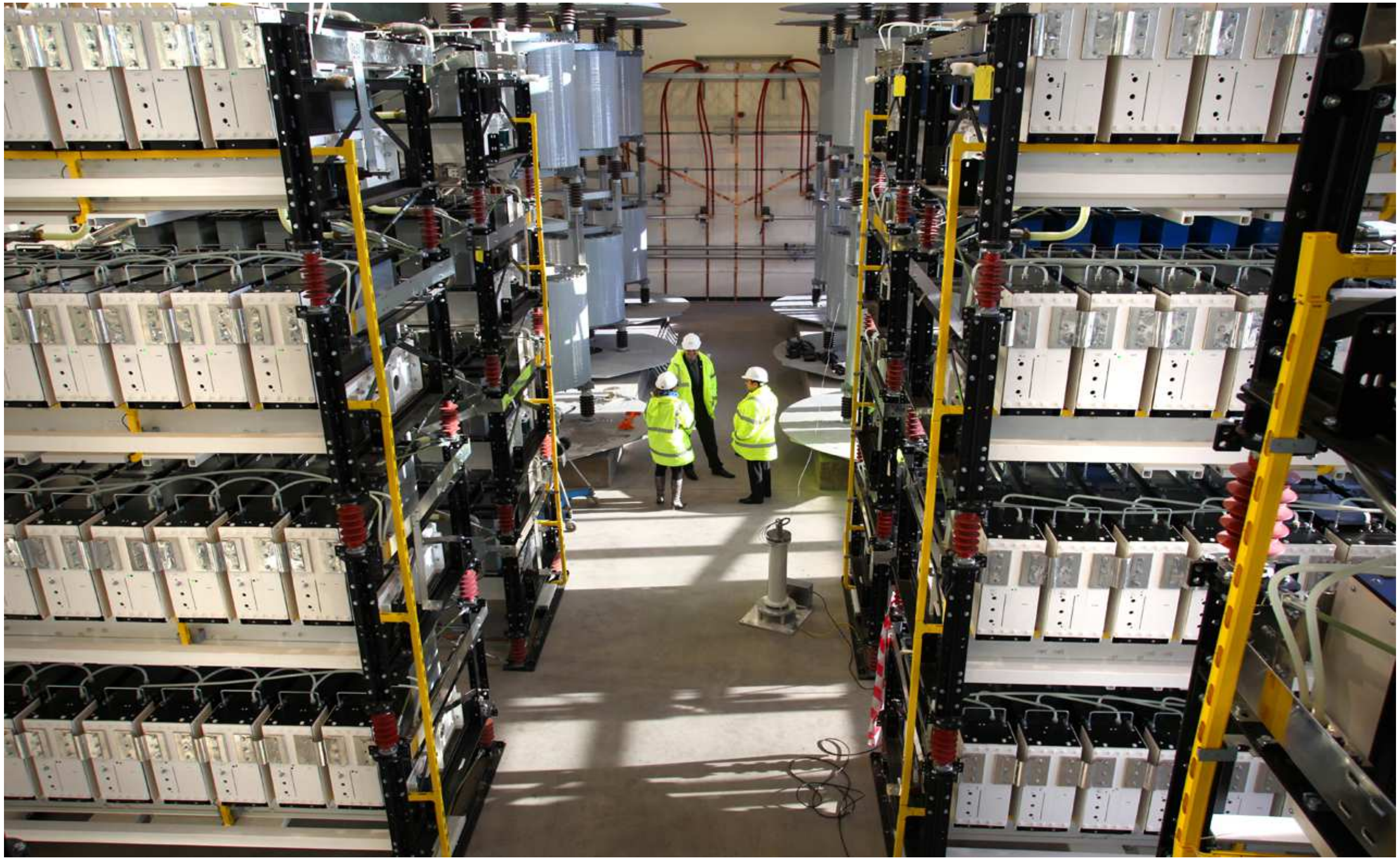




HVDC-VSC technology overview

- **Modular multilevel converters: Manufacturers implementations**

Alstom implemetation



Introduction

Transmission layouts for OWPP

HVDC-VSC technology overview

- Two level converters.
- Three level NPC converters
- Modular multilevel converters

Conclusions

Conclusions

- This presentation has described the current commercial available solutions for energy transmission of offshore wind farms
- For large offshore wind power farms located far from the PCC the most suitable energy transmission layout is based on HVDC-VSC technologies.
- The MMC represent s a really important milestone in the evolution of HVDC-VSC transmission links.

- Future research topics
  - New energy transmission layouts with MVDC collector systems.
  - New converter topologies for HVDC-VSC transmission systems.
  - Development of control algorithms for multiterminal HVDC links.

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