DC collection systems for offshore wind

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CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Contents

- Background
- AC collection systems
- DC collection systems
- Key technologies and challenges
- Case study

➢Background

- Greenhouse gas emissions
- Depletion of resources
- Emission of harmful substances

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Renewable energy policy Goals

- European Union: Carbon Neutral by 2050
- UK: Net-Zero by 2050
- China: Peak carbon dioxide emissions by 2030
  Carbon Neutral by 2060

➢Background

- Wind energy is free and renewable source.

Onshore

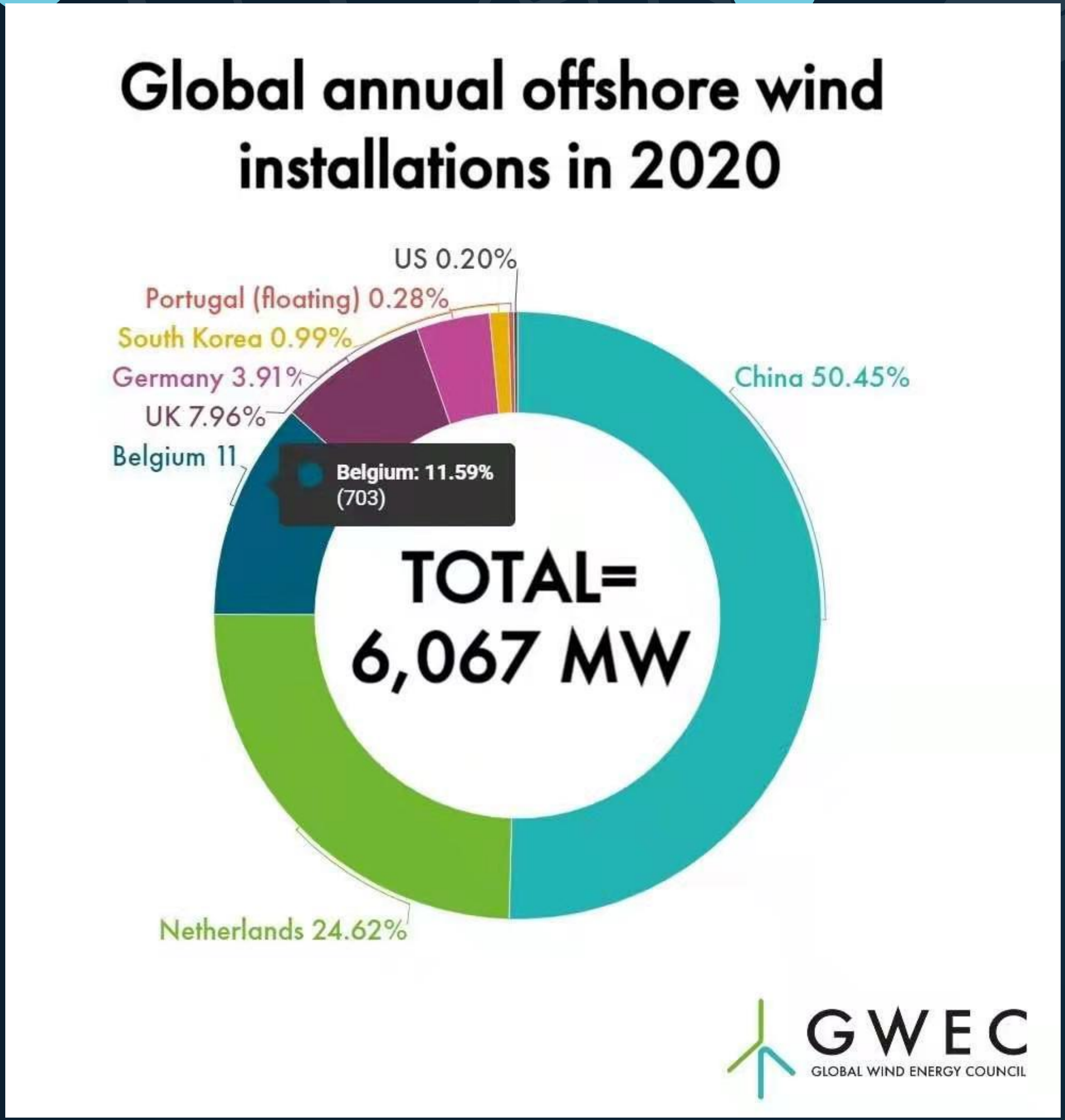
- Limited land resources
- High wind abandonment rate
- Development maturity and saturation
- Difficulty in wind energy absorption

or

Offshore

- Richer wind resources
- No land restrictions
- Higher capacity factor

Background



- *Global annual offshore wind installations in 2020 are more than 6 GW.*
- *The European market maintained steady growth.*
- *China has become the largest market for offshore wind power for the third consecutive year.*
- *The cumulative installed capacity of global offshore wind power is more than 35GW by 2020.*
- *According to OREAC data, the global installed capacity of offshore wind power will reach 1,400 GW by 2050.*

Background

- The UK is still the country with the most installed offshore wind power.

- The annual electricity generation based on the current global installed capacity of offshore wind power

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A reduction of more than 20 million cars on the road.

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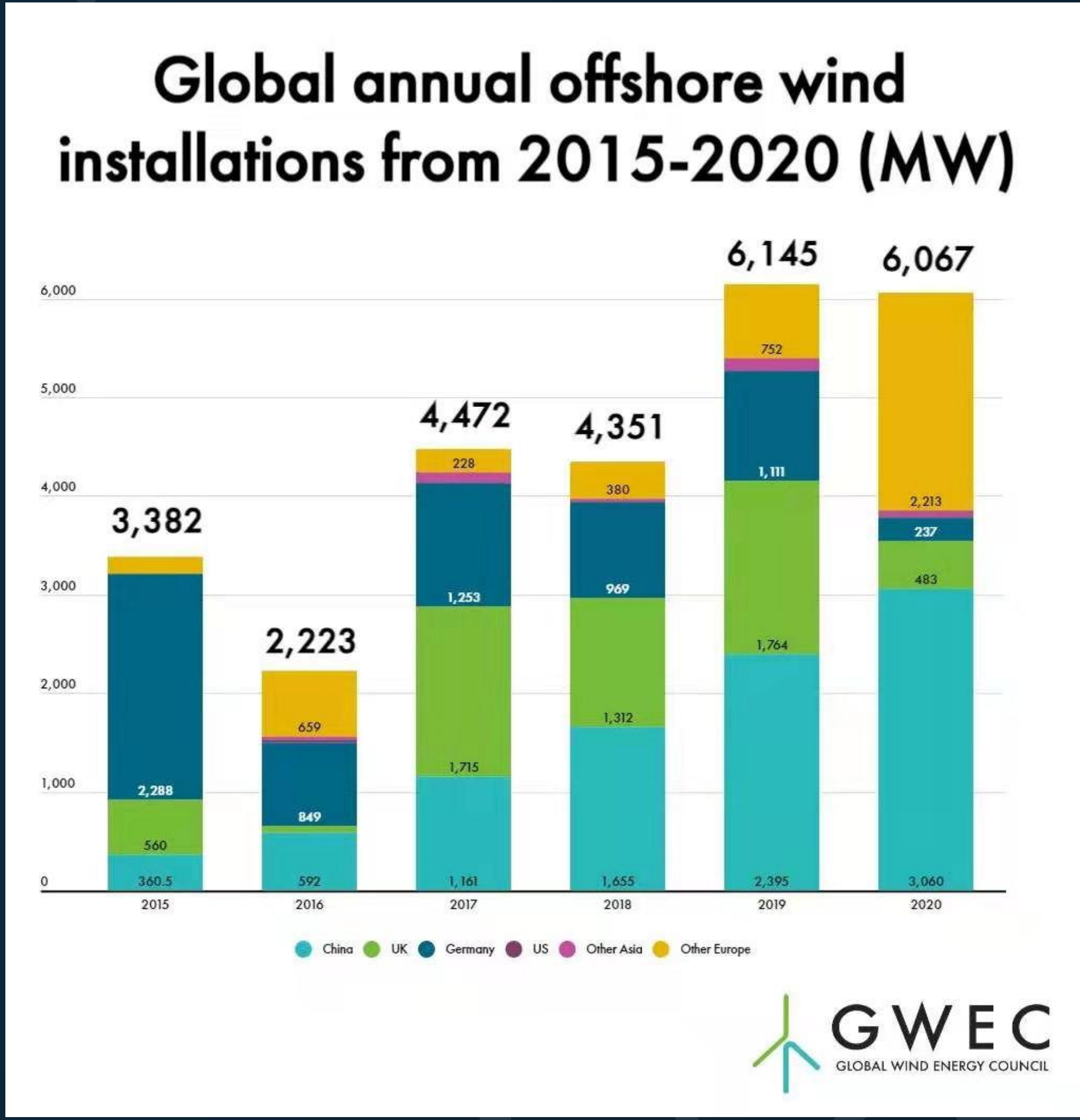
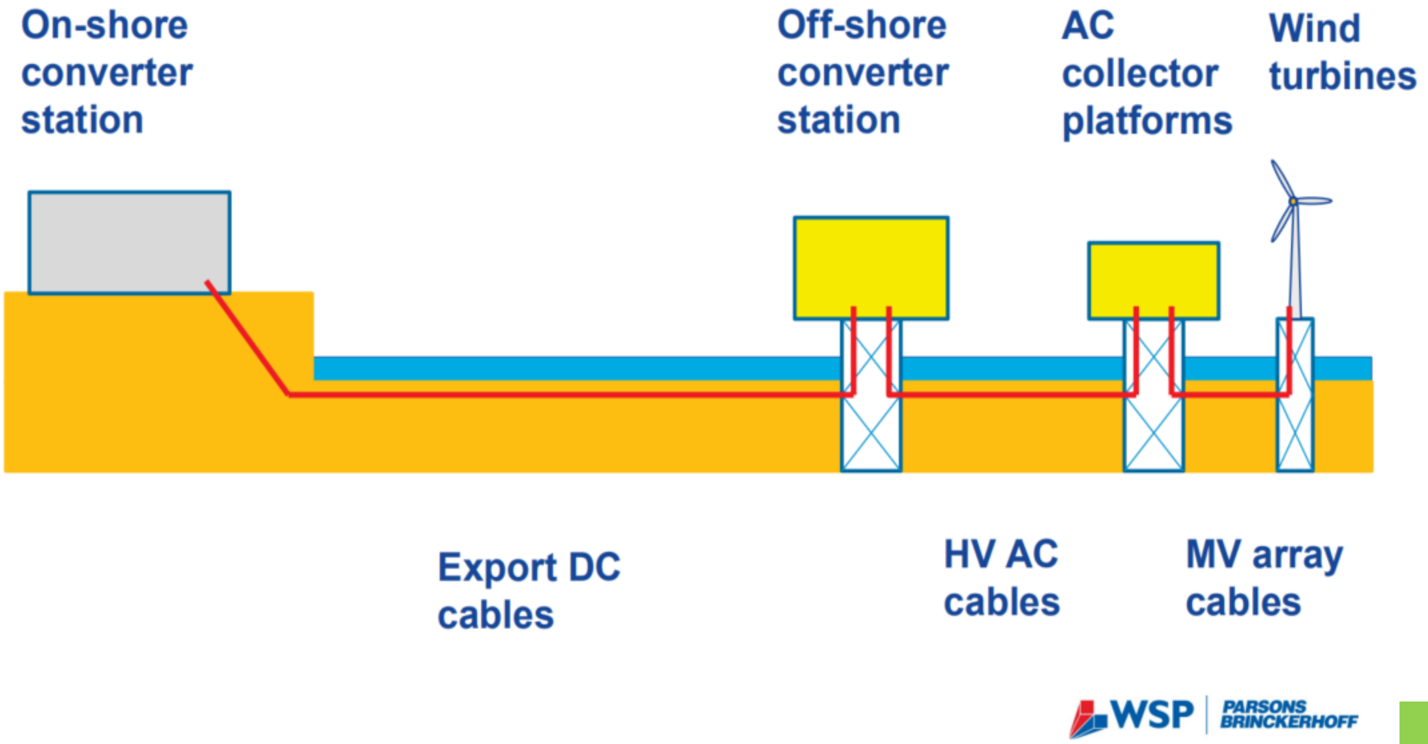
A reduction of 62.5 million tons of carbon emissions



Cumulative installed capacity by 2020 (MW)

UK	China	Other Asia	Germany	US
10206	9898	2505	7730	42

➢Background



Electrical System of an Offshore Wind Farm

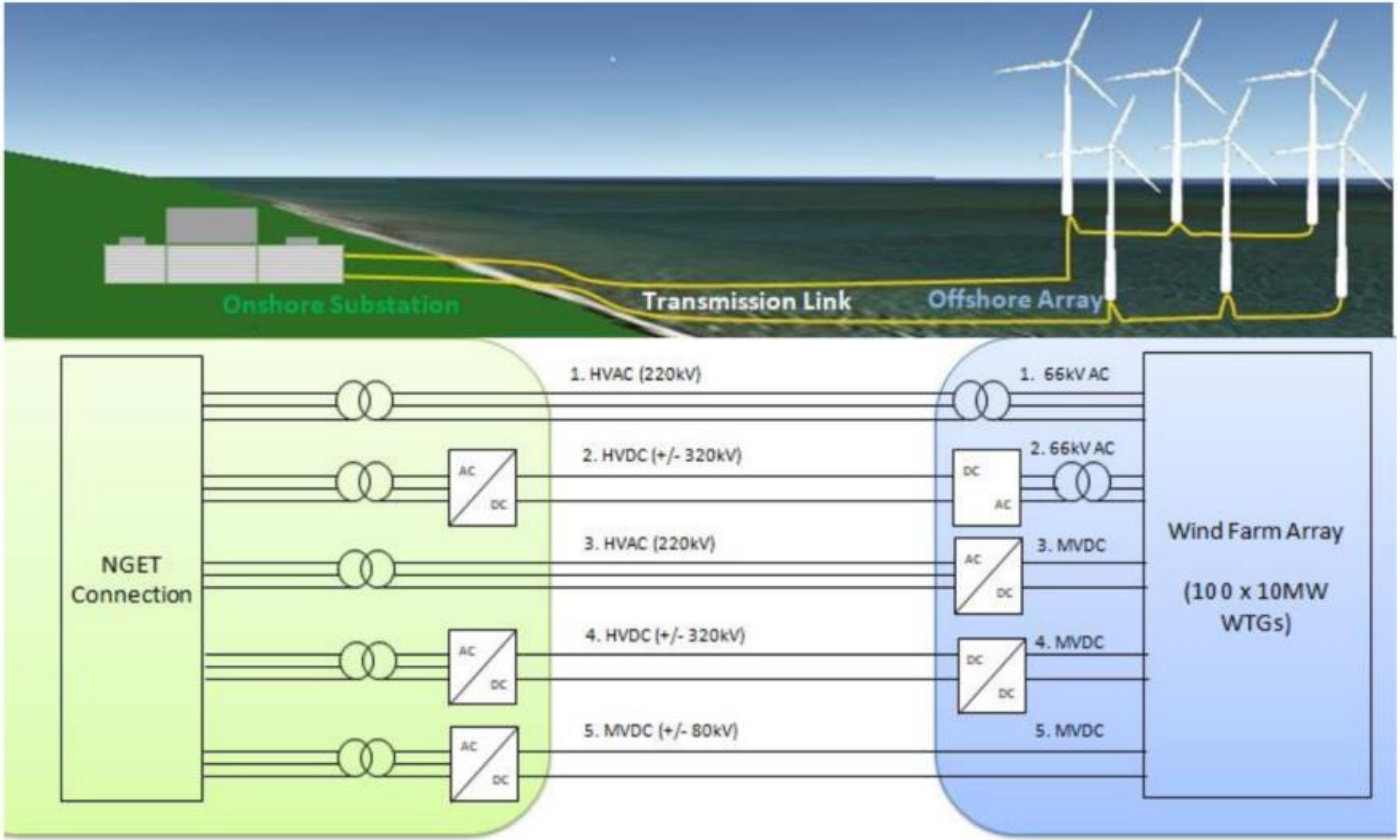
Transmission system:

- HVAC
- LCC-HVDC
- VSC-HVDC
- Hybrid Converter HVDC
- FFTS

Advantages of VSC-HVDC

- No capacitance effect
- Reduce power loss
- Better control capabilities

➢Background



From: Offshore Wind

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AC collection systems

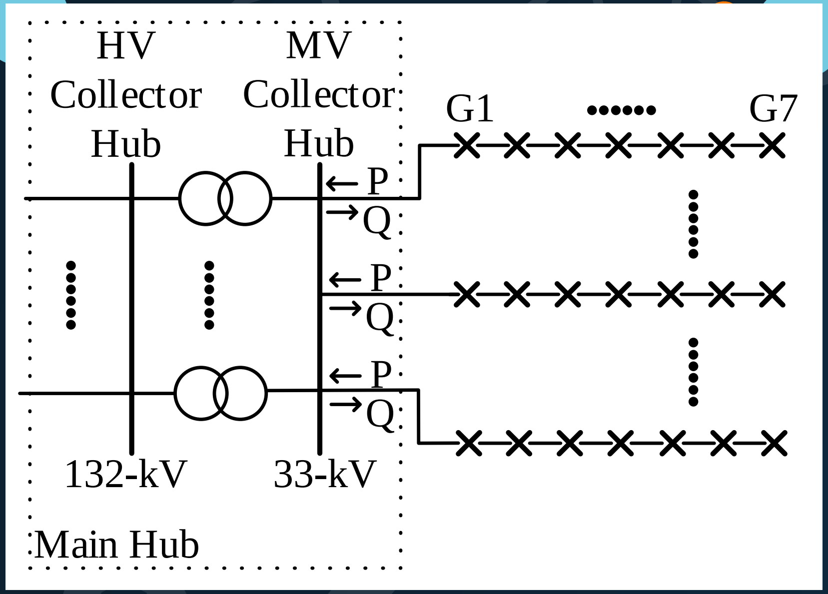
- Typical voltage levels of AC collection systems now：

33-36kV

- Trend of voltage levels of AC collection systems in the future:

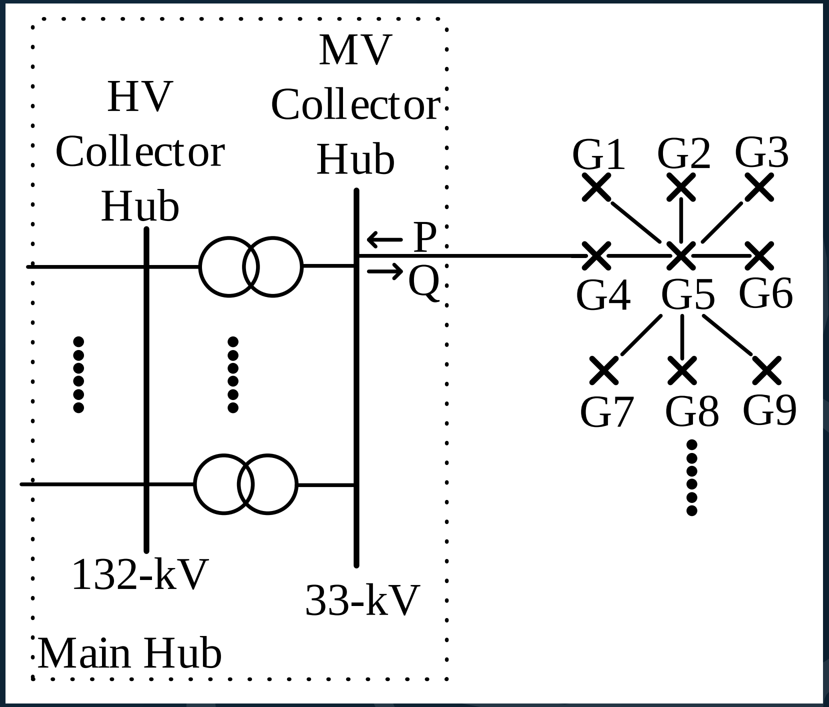
66-72kV

AC collection system

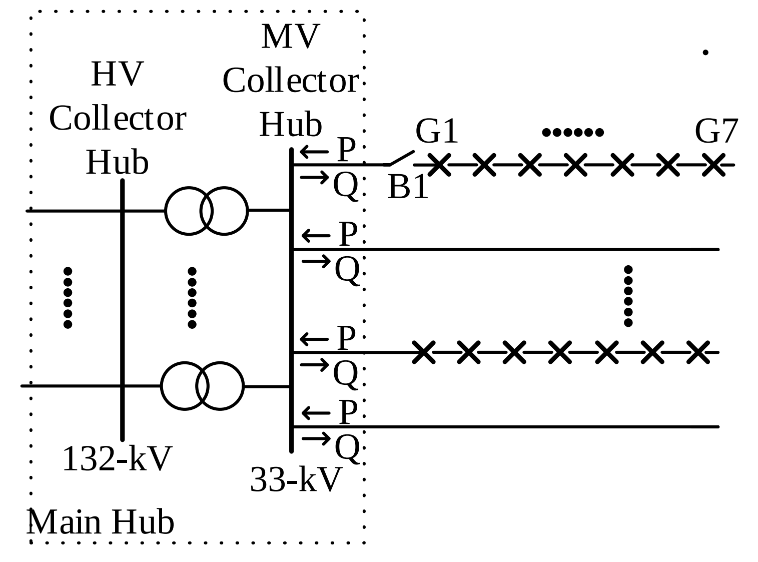


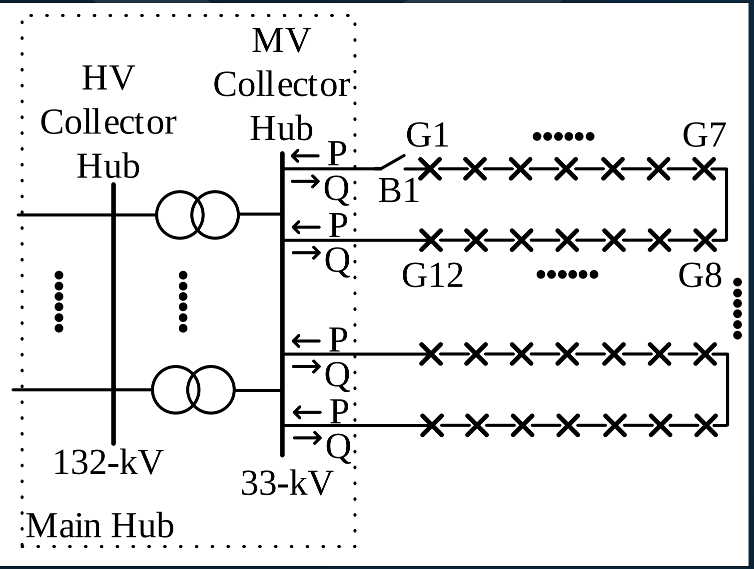
AC Radial topology:
1. low cable costs
2. simple control algorithms
3. poor reliability

AC Star topology:
1. Each turbine is connected to a point of interconnection (star/cluster point) by means of its own cable
2. A way to reduce cable ratings and to provide a high level of security for the entire wind farm
3. More complex switchgear requirement at the wind turbine is the major cost implication



AC collection system





AC Radial loop system:

1. Higher reliability compared to the simple radial system
2. Require more complex control system depending on location and number of reconfiguration switches
3. Can be reconfigured in case of faults

Reactive power compensation plays an important role in AC collection systems.

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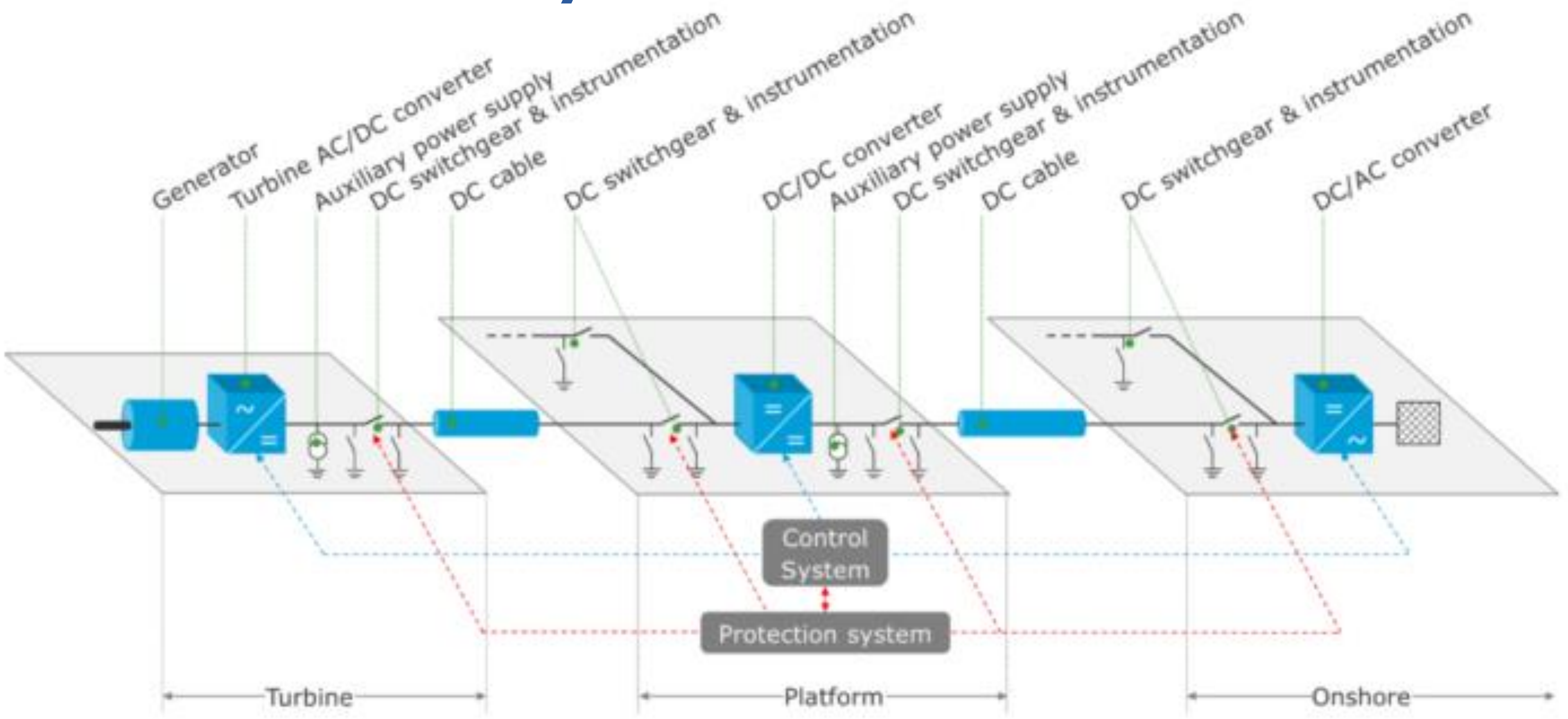
➢DC collection systems

Motivations:

- With increase of wind turbine rating and longer collection distance, DC collection system is more preferable than AC collection system.
- Save bulky power frequency transformers and redundant substation links and reduce the load on offshore platforms.
- Using DC cables does not require reactive power, thus get the advantages of lower losses, larger transmission capacity and more material saving.
- The converter voltage grade is more flexible.

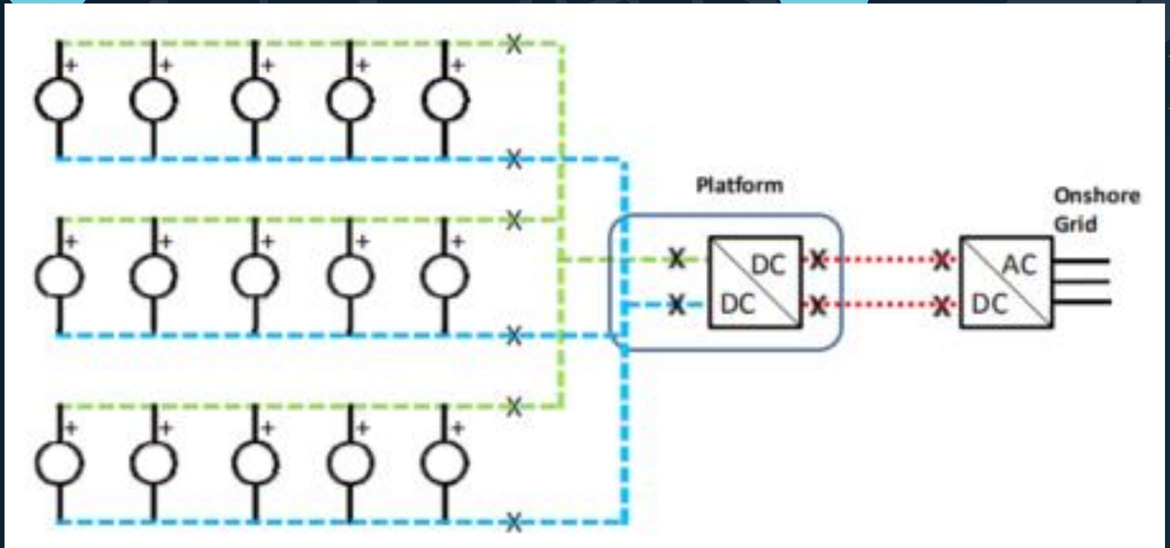
➢DC collection system



General topology for an offshore wind farm with DC connection

From: Offshore Wind Accelerator

DC collection system



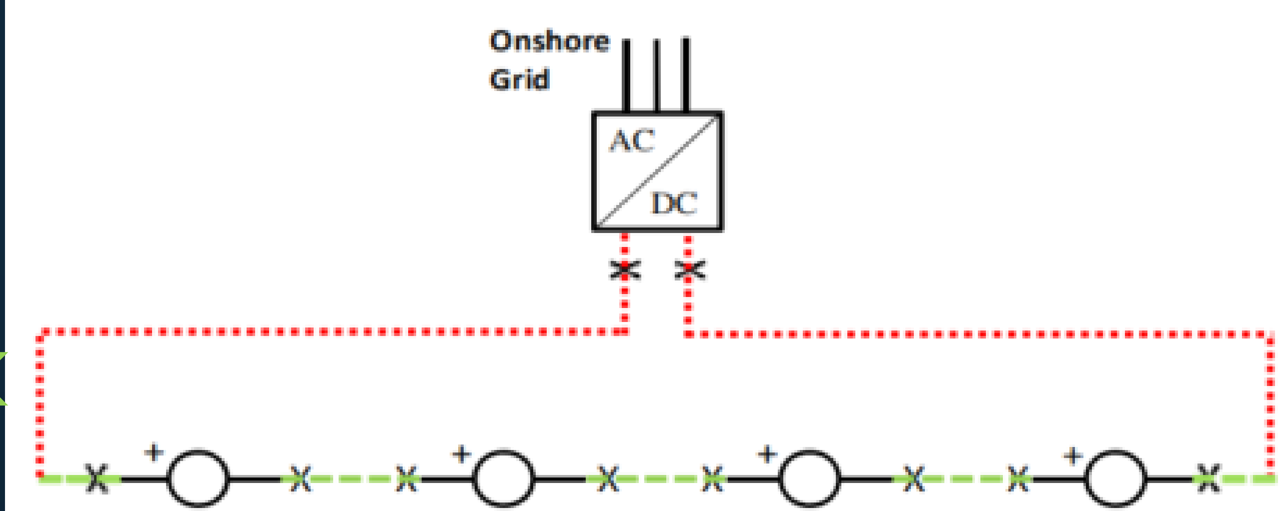
DC parallel topology:

1. Require DC/DC converter platform
2. The output voltage of WT is MVDC
3. This topology is also named DC radial topology.

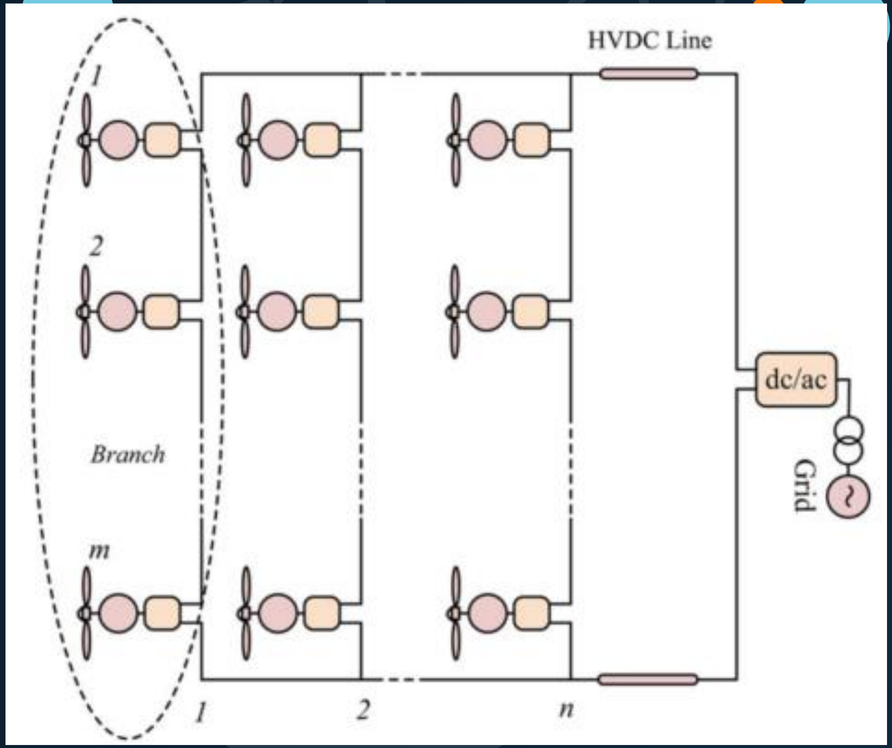
DC star topology requires more DC circuit breakers, but DC circuit breakers are not yet mature. So no scholars proposed this topology.

DC series topology:

1. No DC/DC converter platform
2. Strong coupling characteristics and insulation withstand voltage problems between WTs in series
3. Overvoltage problem

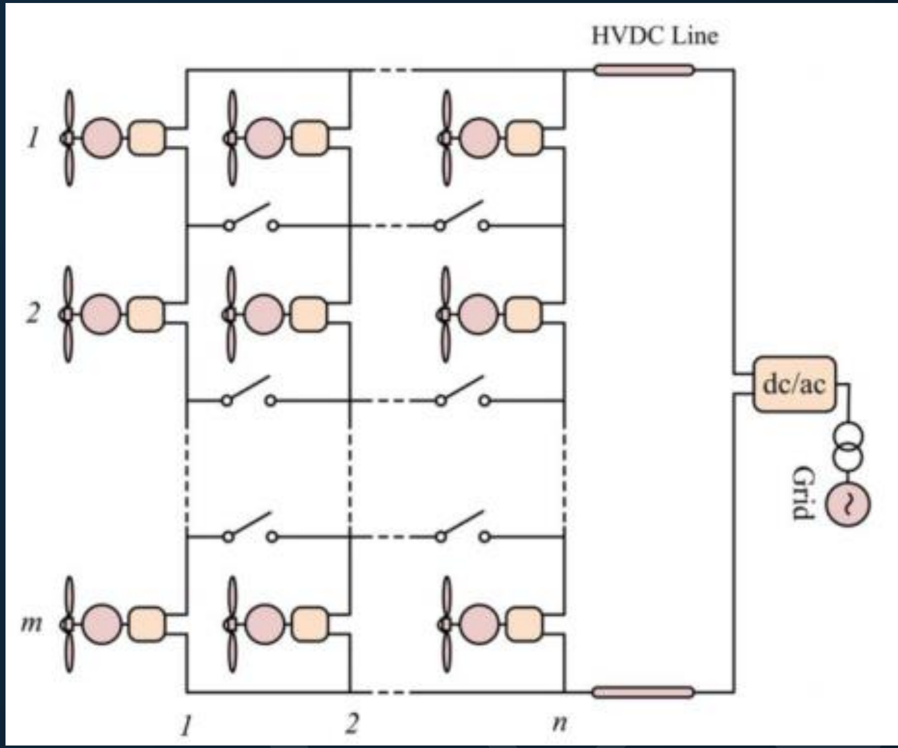


DC collection system



DC series-parallel (SP) topology:

1. More energy harvest compared to DC series topology
2. Overvoltage problem



DC matrix interconnected (MI) topology:

1. More switches, higher cost
2. Solve the overvoltage problem of SP topology
3.Complicated control

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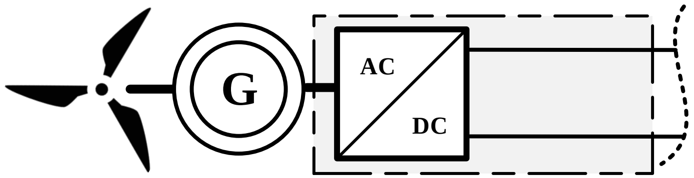
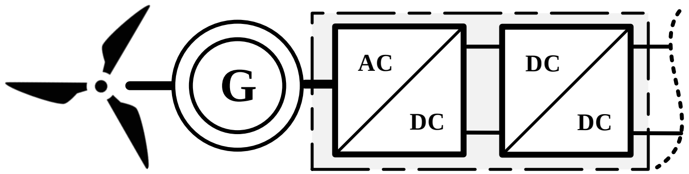
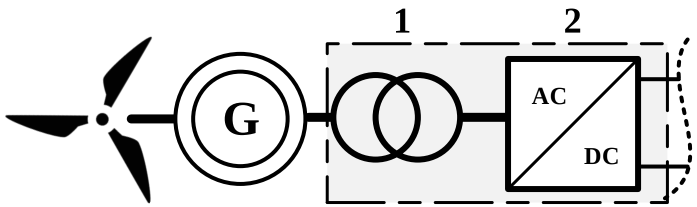
➢ Key technologies-DC WT



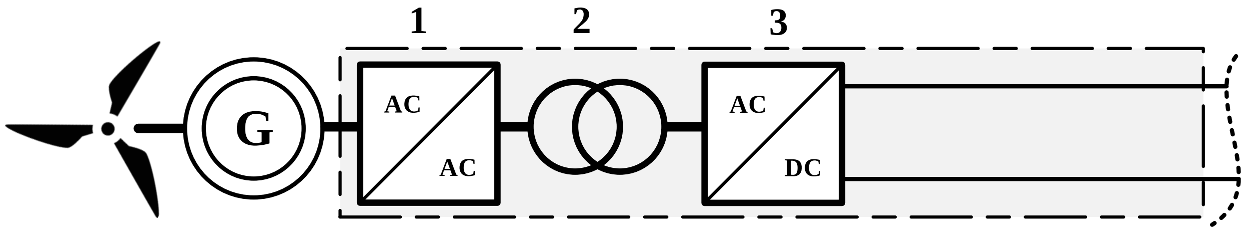
(a) Active rectified based DC WT



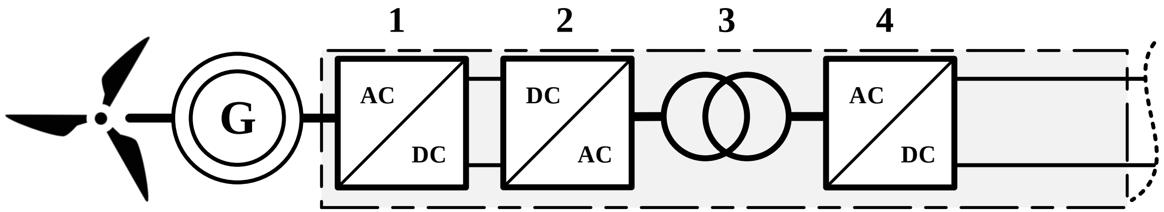
(b) Non-isolated DC/DC converter based DC WT;



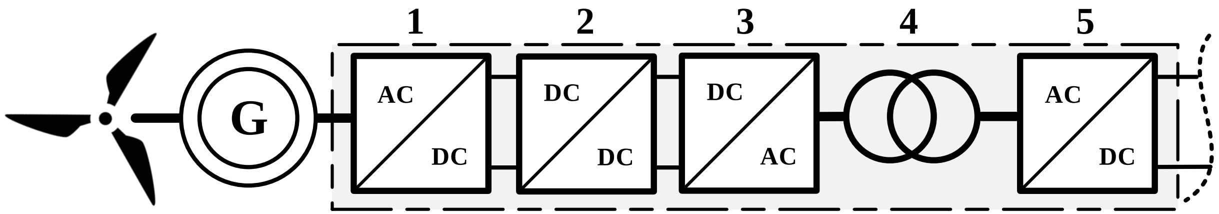
(c) AC transformer and passive rectifier based DC WT;



(d) Matrix converter, medium frequency transformer and passive rectifier based DC WT;

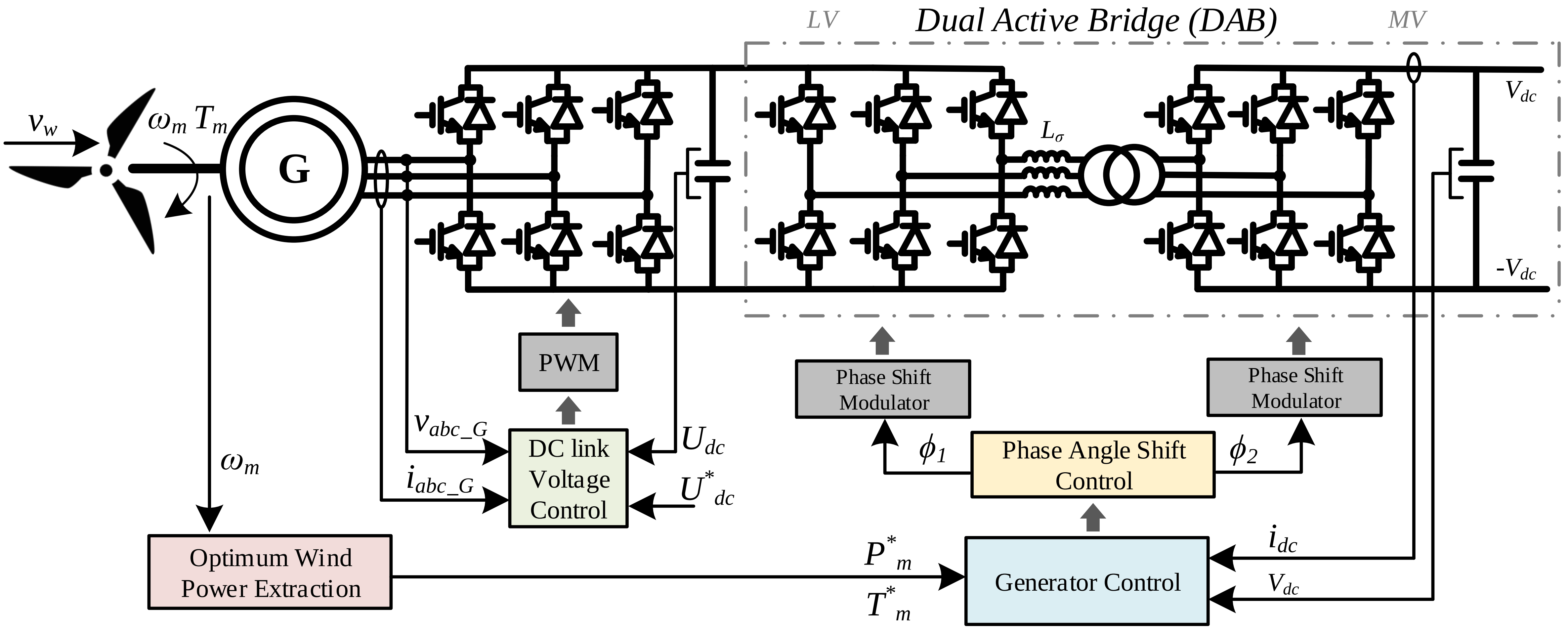


(e) Active rectifier and galvanic isolated DC/DC converter based DC WT;



(f) Boost converter between the active rectifier and galvanic isolated DC/DC converter based DC WT.

➤ Key technologies-DC WT

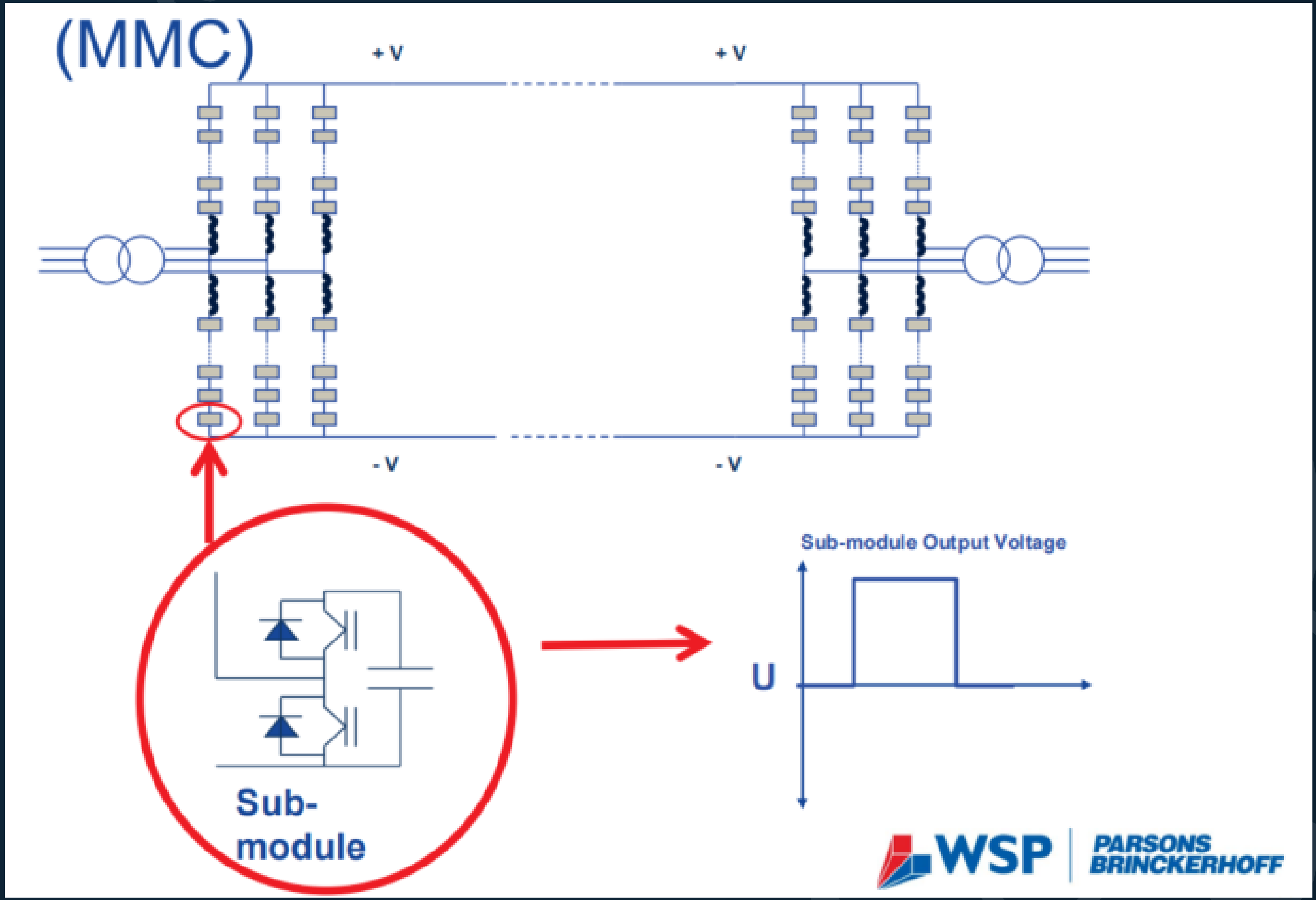


Control scheme of DCWT topology-(e).

Key technologies-DC/DC Converter

MMC has the advantages of high input and output withstand voltage, low voltage stress of power switching devices, high reliability, flexible control, etc.

The application of MMC to achieve DC/DC conversion is an inevitable choice for high-voltage, large-capacity DC/DC converter technology.



Key technologies-DC cable

Mass impregnated cables

Self-contained fluid filled cable

Extruded cable

Key technologies- protection and control

- DC circuit breaker needs to cut off the fault current within 2~5ms quickly and reliably.
  DC circuit breakers include solid-state circuit breaker and mechanical circuit breaker and hybrid circuit breaker.
  At present, no mature DC circuit breaker products have been put into engineering practice.

- DC based wind turbines and DC-DC converters must be controlled in order to comply with stringent grid code requirements, which might require novel control methods in DC based wind farms for various parallel and series topologies.

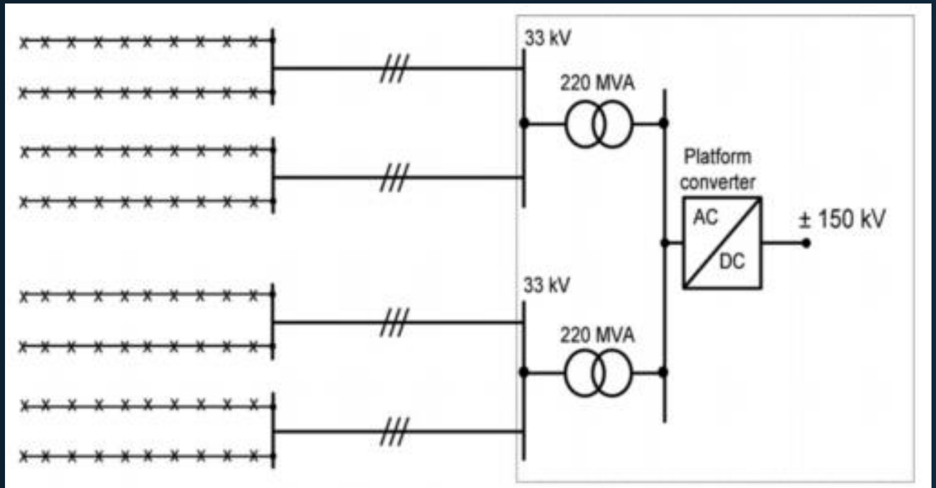
➢ Key challenges

Technology			Maturity status
DC wind turbine	DC WT integration		Immature
	WTG		Mature
	WT Converter	AC-DC	Semi-mature
		DC-DC	Immature
	DC switchgear		Early stage
DC-DC converter			Early stage
DC circuit breaker			Semi-mature
MVDC cable			Mature

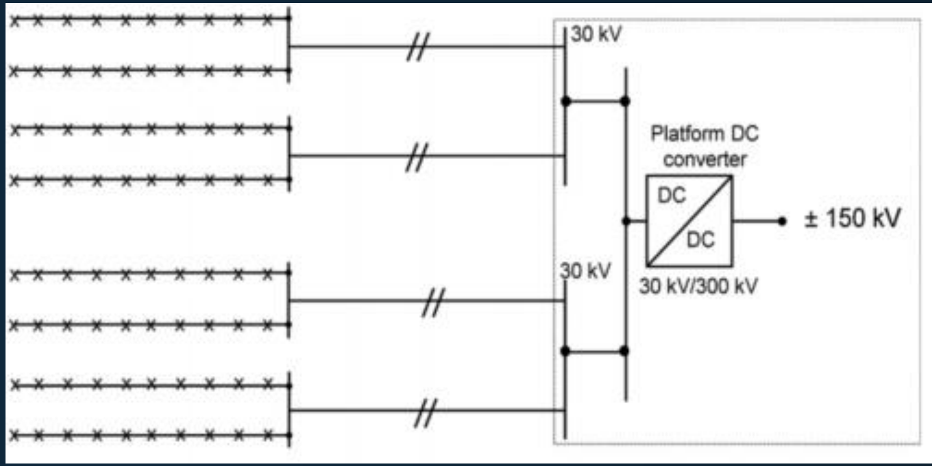
From: Offshore Wind Accelerator

Key challenges

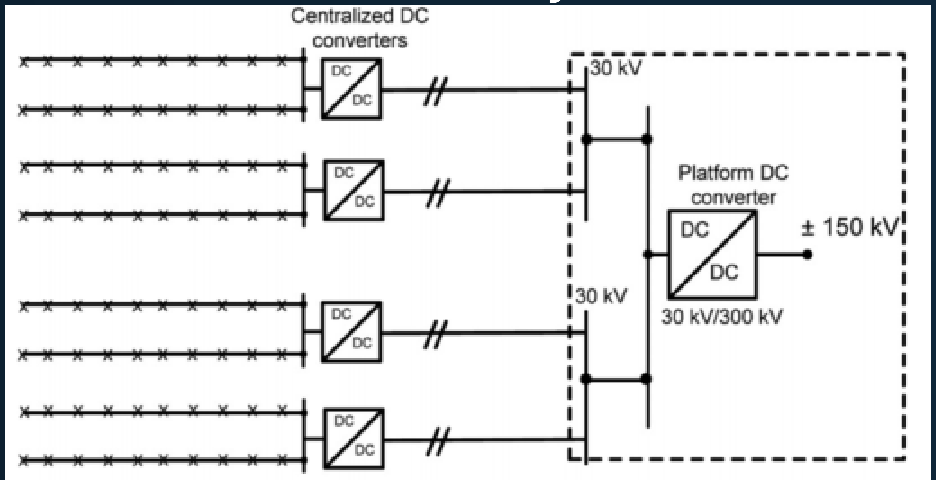
- The economics and reliability of DC collection systems



AC collection system



DC1 collection system



DC2 collection system

Compare the economics of three topologies of AC collection and DC collection systems

Key challenges

Cost estimation 5 km collection cable length.

Case	cost (M£)						Total cost (M£)
	Collection type	Turbine power electronics	Collection cables	Platform	Protection	Cost of losses	
400 MW	AC	55.44	65.63	101.70	8.40	53.47	284.64
	DC1	76.00	32.98	90.68	72.97	55.14	327.77
	DC2	24.00	32.98	172.38	61.76	54.34	345.46
200 MW	AC	27.72	32.82	52.05	4.20	26.57	143.36
	DC1	38.00	16.49	45.94	36.49	27.95	164.87
	DC2	12.00	16.49	87.09	30.88	27.22	173.68

!

DC collection system is still more expensive than AC collection system.

There is no actual operation data of DC collection system and its reliability can not be accurately evaluated.

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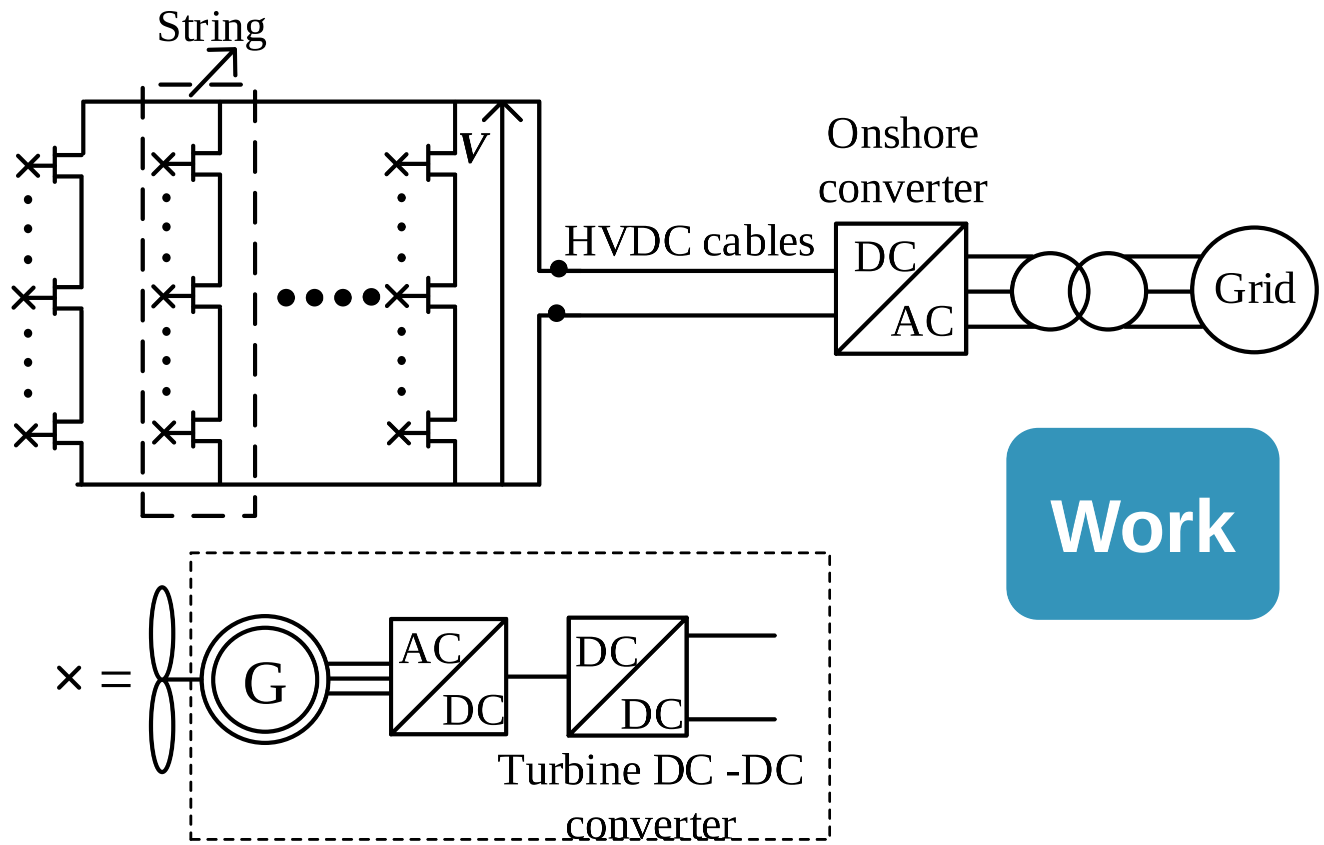
➤ Case study



Configuration of DC series-parallel collection systems

Work

1. The annual energy curtailment due to the over-voltage limits of turbine DC/DC converters is analysed for a 200MW DC series–parallel wind farm.

2. The impact of wake effects on the energy curtailment losses is quantified and demonstrated with the case study

- Lakshmanan P , Guo J , Liang J ," Energy curtailment of DC series-parallel connected offshore wind farms," IET Renewable Power Generation, vol. 12, no. 5, pp. 576-584, 2018.

➢ Case study

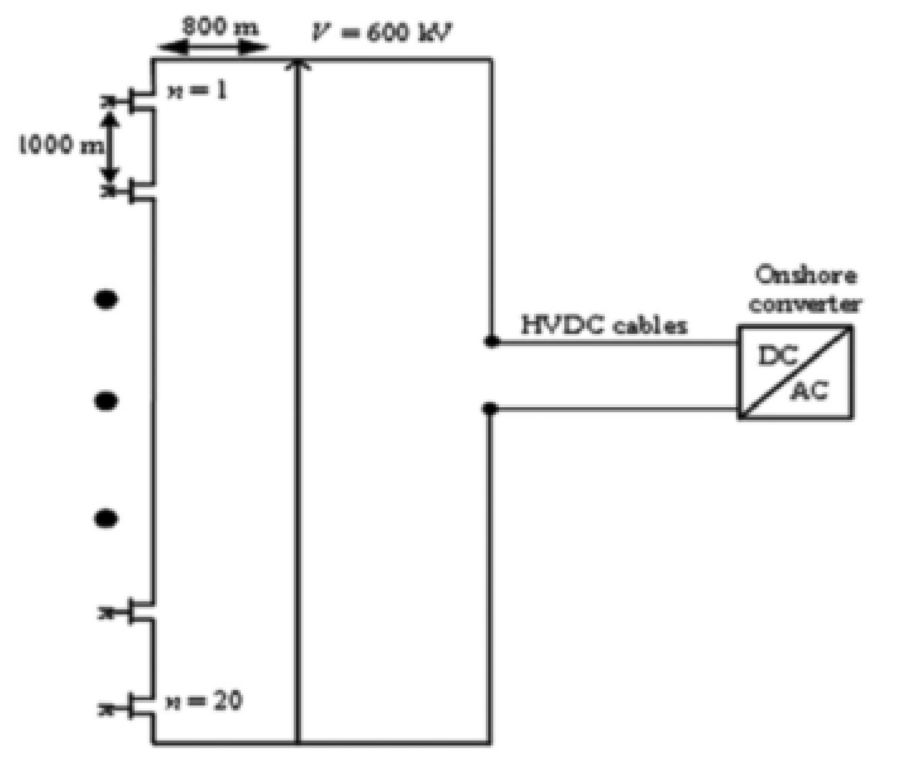
Challenge!

- In the case of a DC series–parallel connected offshore wind farm, the individual wind turbines cannot be operated at maximum power all the time.
- Some of the series connected wind turbines with high output power experiencing over-voltage and wind turbines with low output power experiencing under-voltage at their DC outputs.
- The over-voltage and under-voltage conditions can be limited by curtailing the power output of the wind turbines with high output power, which will result in loss of wind power.

Case study

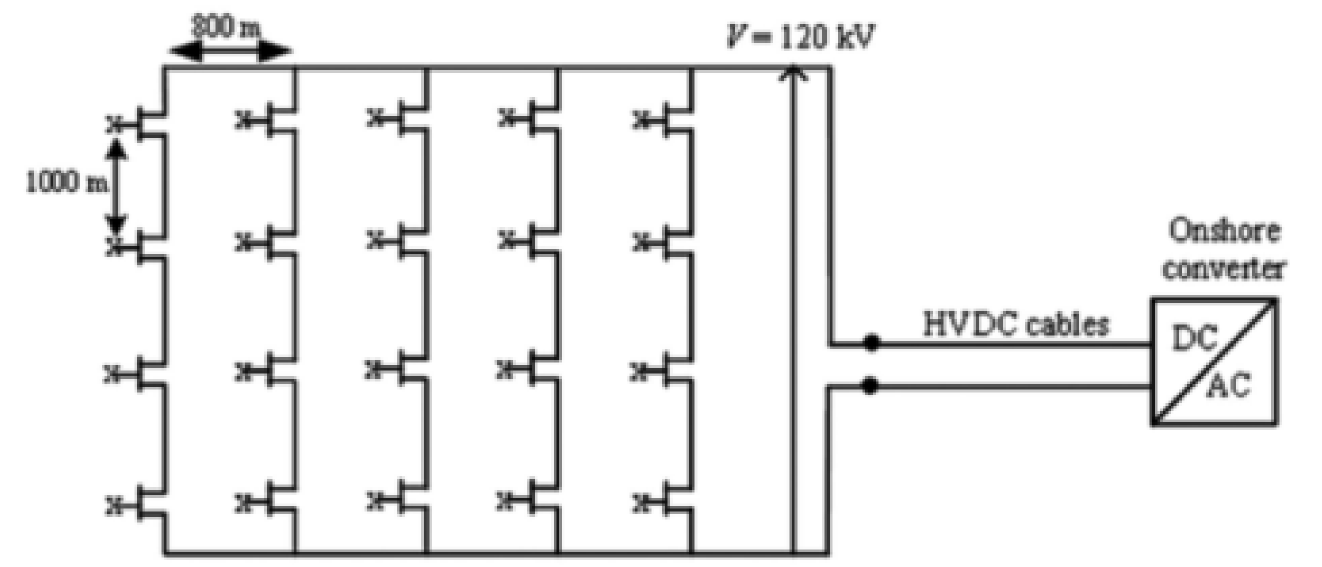
Two cases with different number of series connected turbines are considered to find the influence of different number of series connected turbines on energy curtailment losses

Case 1



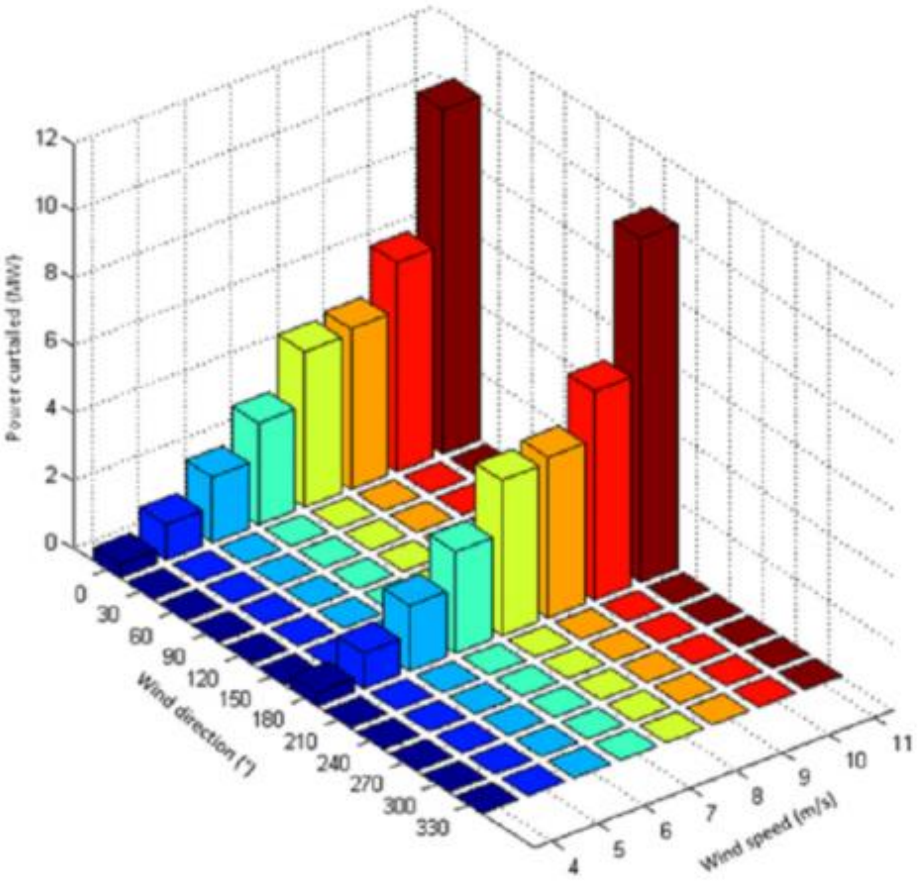
Case 1: 20 X1 turbines V = 600 kV

Case 2

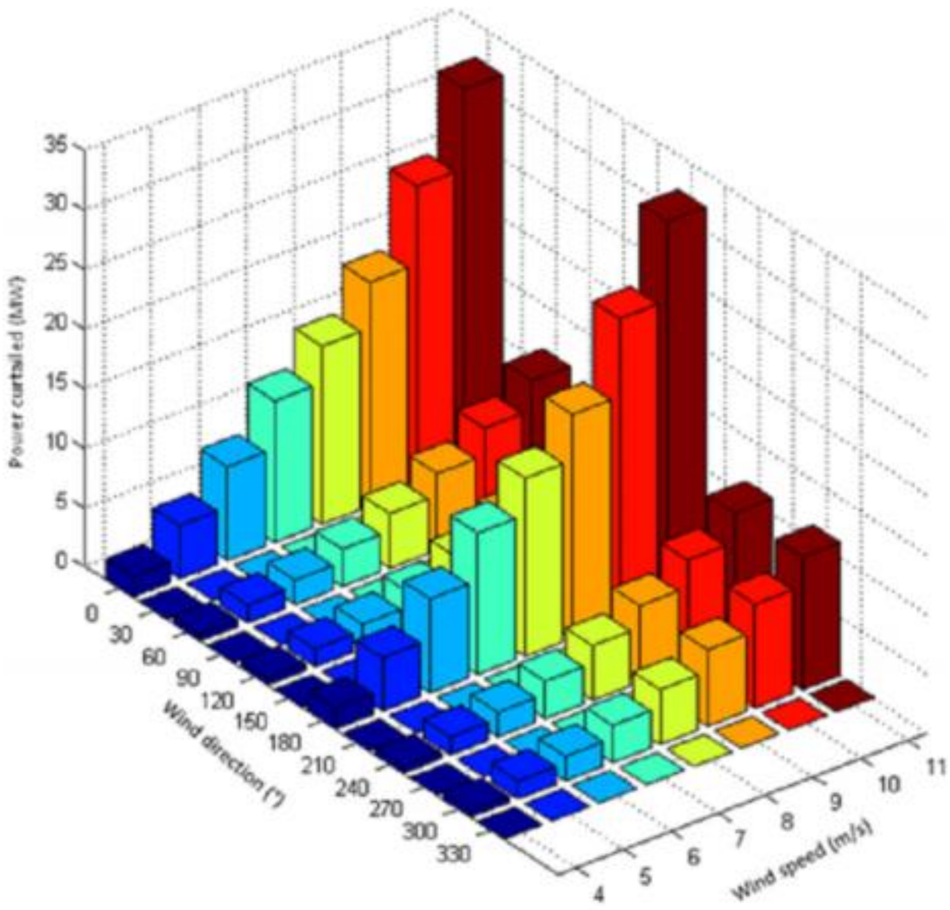


Case 2: 4 X5 turbines V = 120 kV

➢ Case study



Case 1 (20 X1)



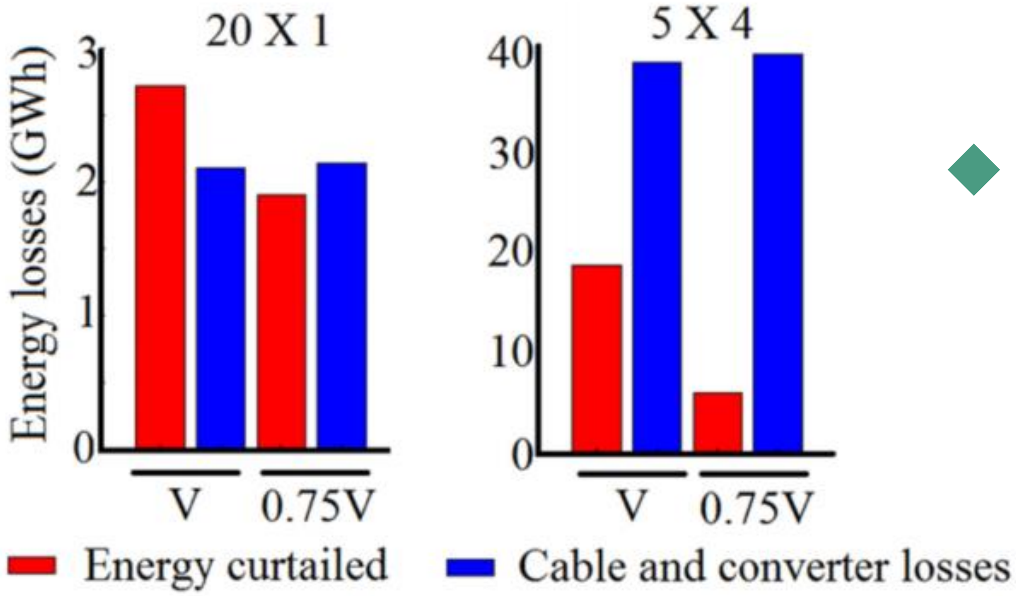
Case 2 (4 X 5)

Total power curtailment losses of all the strings for case 1 (20 × 1) and case 2 (4 × 5) under different wind-speed and wind direction scenario

➢ Case study

Table 2 200 MW DC series–parallel wind farm – Annual energy production 960.02 GWh

Case	Annual wake losses	Nominal string voltage V: Annual energy curtailment losses GWh, %	Nominal string voltage V: Collection cable and turbine DC–DC converter losses GWh, %	String voltage reduced up to 25%: Annual energy curtailment losses GWh, %	String voltage reduced up to 25%: Collection cable and turbine DC–DC converter losses GWh, %
case 1 (20 × 1)	34.3879 (3.58%)	2.7154 (0.28%)	2.1041 (0.219%)	1.8977 (0.20%)	2.1370 (0.223%)
case 2 (4 × 5)	132.9135 (13.84%)	18.7045 (1.95%)	38.8765 (4.0495%)	5.9247 (0.62%)	39.6679 (4.132%)



◆ **Reducing the string voltage to decrease power curtailment losses can be considered useful.**

➢ Case study

Table 3 200 MW DC series–parallel wind farm, wind turbine failure case study

Total curtailment losses MW, two wind turbines failed				Total curtailment losses MW, one wind turbine failed			
case 1 (20 x1 turbines)	loss of power due to string failure	V reduced to avoid string failure (594 kV)	V reduced up to 25%	case 2 (4 × 5 turbines)	loss of power due to string failure	V reduced to avoid string failure (99 kV)	V reduced up to 25%
two lowest power turbines failed	1.6636 (1.5181%)	0.3703 (0.3379%)	0.2486 (0.2268%)	lowest power turbine failed	5.9959 (5.4712%)	1.5363 (1.4019%)	1.0461 (0.9545%)
two highest power turbines failed	1.3667 (1.2471%)	0.0742 (0.0677%)	0.0176 (0.0161%)	highest power turbine failed	5.2436 (4.7848%)	1.3132 (1.1983%)	0.5794 (0.5287%)

- The amount of power lost due to string failure can be reduced from 5.9959 to 1.5363 MW for the lowest power turbine failed condition and from 5.2436 to 1.3132 MW for the highest power turbine failed condition by reducing the string voltage to 99 kV.
- This is the value of string voltage just to avoid string failure with the remaining three turbines and their 10% over-voltage limits.
- The amount of power lost due to string failure could further be reduced by reducing the string voltage up to 25%.

➢ Case study

Table 4 Over-voltage ratings of turbine DC–DC converter specified for $N_{max} = 1$ in (19)

Case	20 × 1 V = 600 kV	4 × 5 V = 120 kV
over-voltage ratings of turbine DC–DC converters $V_N(1 + \alpha_u)$	31.6 kV	40 kV
α_u	5.3%	33.3%

Another way to avoid string failure conditions is to provide an over-voltage rating of turbine DC–DC converters depending on the number of series connected turbines and number of turbines allowed being lost from the string.

Case study

Reducing the string voltage is useful to reduce the energy curtailment losses, and the reduction in the power curtailment losses is greater than the increase in the collection cable and turbine DC–DC converter losses.

Results

Reducing the string voltage can help to reduce the power losses caused by string failure condition.

DC series–parallel collection systems can be alternative in achieving reduced foot-print and weight of offshore wind farms in spite of the curtailment losses.

Q & A

THANK YOU FOR YOUR TIME!