Chapter 3

Offshore Wind Farms

In this chapter an overview of the current technology of the offshore wind farms is performed. This survey is focused into the two main parts of the offshore wind farms electric connection infrastructure: the energy collector system (the inter-turbine medium voltage grid) and the energy transmission system, which are separately evaluated in the present chapter.

Firstly, the AC and DC transmission options to carry the energy from the offshore wind farm to the main grid are described and then, a discussion about the advantages /disadvantages of those AC and DC transmission options is performed. The discussion about the best transmission option is based on the rated power of the wind farms and their distance to shore.

As for the energy transmission system, for the energy collector system of the wind farm, the different configuration options are described. However, for the energy collector grid only AC configurations are taken into account.

In this way, the spatial disposition of the wind turbines inside the inter-turbine grid, the cable length between two wind turbines or the redundant connections of the inter-turbine grid are analyzed.

3.1 Historic overview of offshore wind farms

The fast growth of the onshore wind power in Europe, a small and populated area, has led to a situation where the best places to build a wind farm onshore are already in use. However, in the sea, there is not a space constraint and it is possible to continue installing wind power capacity.

The first country to install an offshore wind farm was Denmark in 1991. In the same decade, Netherlands also installed some wind farms very close to shore. So, offshore wind farms are a recently developed technology.

At the early 90s they were very little 6 MW of average rated power, built in very low water depths and with small wind turbines.

However, after this first steps, offshore wind farms are being installed in deeper and deeper waters. Thus, at the end of the 2000s the average water depth of new wind farms multiplied by three, see Figure 3.1.

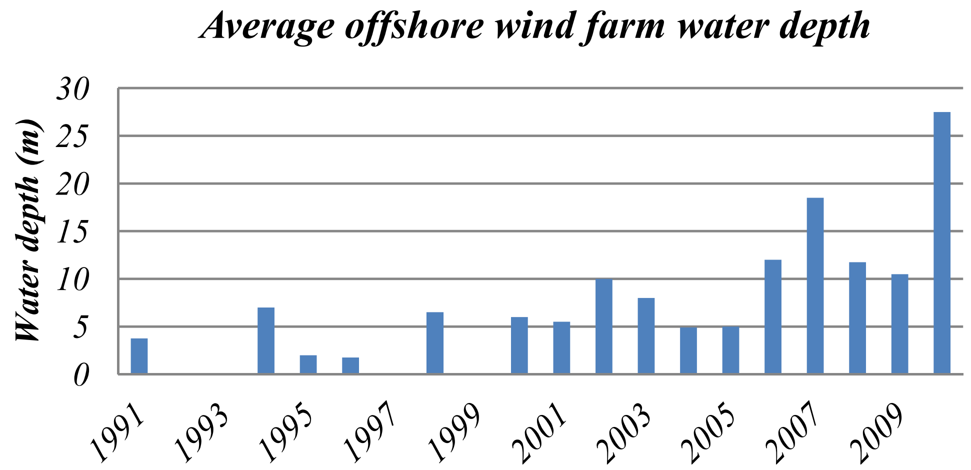


Figure 3.1 Evolution of the average offshore wind farms water depth [23].

But, not only is increasing the average water depth of the wind farms. As the developers are gaining experience / technology in this field and there are more constructed examples. The wind farms are being constructed with bigger rated powers and at locations with longer distances to shore. Thus, from 90s to the next decade the average rated power of installed new offshore wind farms has been multiplied by 15, see Figure 3.3. In parallel with the growth of the average wind farms capacity, the average distance to shore of the wind farms increases as well, see Figure 3.2.

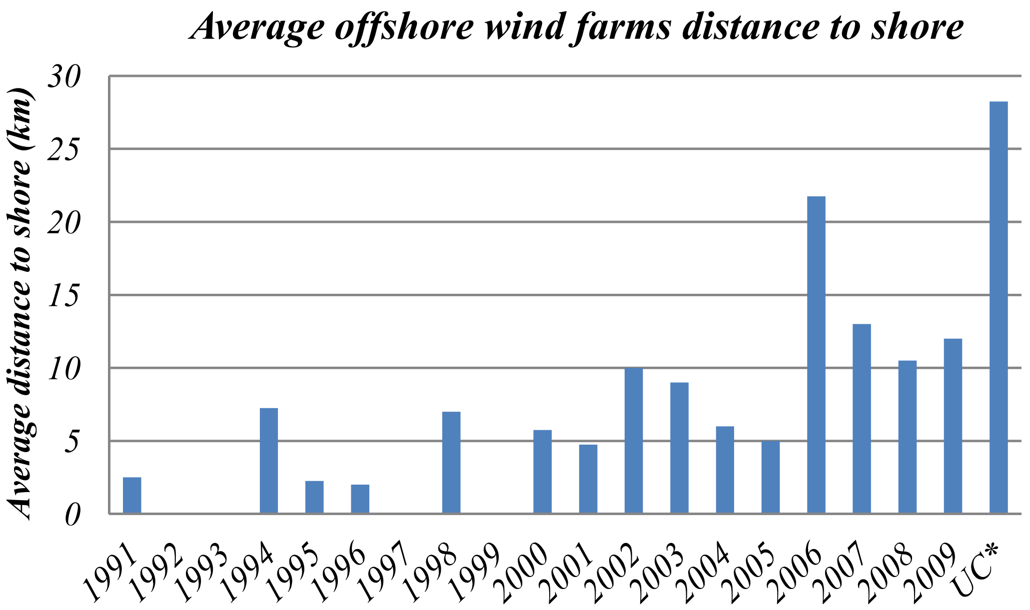


Figure 3.2 Evolution of the average offshore wind farms distance to shore in km [23].

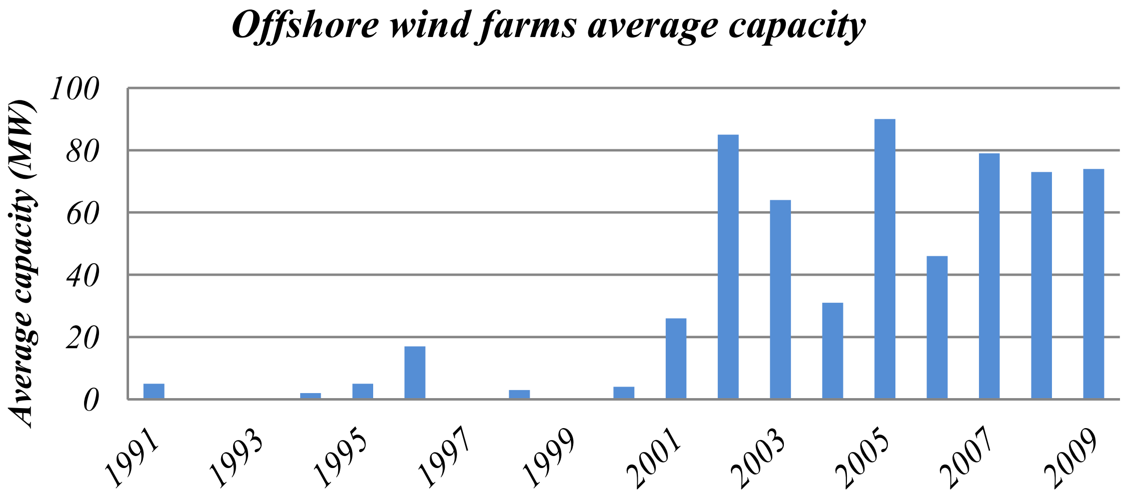


Figure 3.3 Evolution of the offshore wind farms average capacity in MW [23].

As a result, all the biggest offshore wind farms currently in operation are been opened the last few years. Furthermore, four of the five biggest offshore wind farms have been opened during 2010, see Table 3.1

Name	*Country*	*Year*	*Nº of turbines*	*Length to shore (Km)*	*Rated power (MW)*
Thanet	UK	2010	100	7.75	300
Horns Rev 2	Denmark	2009	91	30	209.3
Nysted II/ Rødsand II	Denmark	2010	90	23	207
Robin Rigg	UK	2010	60	9.5	180
Gunfleet Sands	UK	2010	48	7	172.8
Nysted / Rødsand 1	Denmark	2003	72	8	165.6
Belwind phase 1	Belgium	2010	55	48,5	165
Horns Rev 1	Denmark	2002	80	14	160
Prinses Amalia	Netherlands	2008	60	23	120
Lillgrund	Sweden	2007	48	10	110.4
Egmondaan Zee	Netherlands	2007	36	10	108
Inner Dowsing	UK	2008	27	5	97.2
Lynn	UK	2008	27	5.2	97.2

Table 3.1 Biggest constructed offshore wind farms in EU.

Despite those examples, today the most of the offshore wind farms have a relatively small capacity (<60 MW) and are located relatively close to shore (less than 20 Km), but as is been listed before, also pretty huge wind farms (100-300MW) have been built al locations far away into the sea (> 45 Km).

The new offshore wind farms and offshore wind farm projects are bigger and bigger and at longer distances. As can be seen in Figure 3.4 based on the characteristics of built offshore wind farms which summarize the previous Figure 3.2 and Figure 3.3.

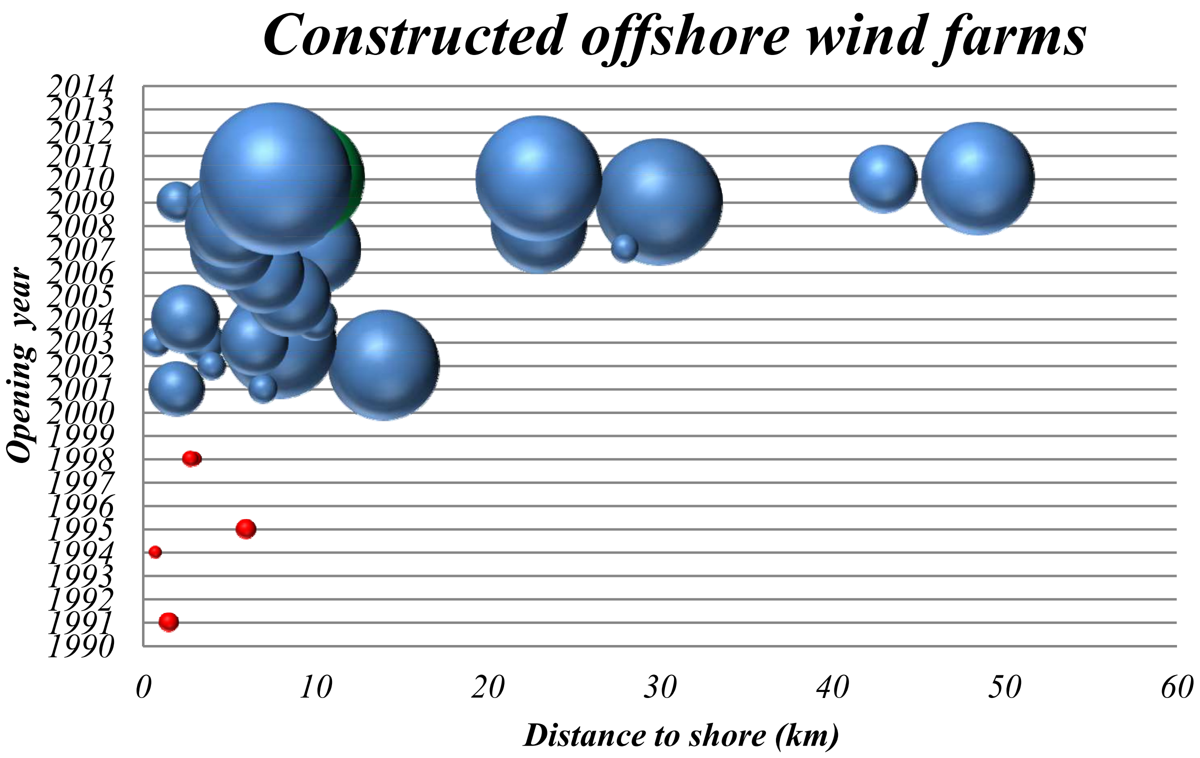


Figure 3.4 Constructed offshore wind farms, rated power (size of the bubbles) depending on the distance to shore and opening year. Offshore wind farms opened in 90s (Red bubbles) and offshore wind farms opened in 2000s (blue bubbles).

Furthermore, according to [24] this trend will continue or will increase in upcoming years, as shown in Table 3.2.

	90s	*2000s*	*2010-2030*
Countries with offshore wind	3	7	20+
Average wind farm size	6 MW	90 MW	>500 MW
Average yearly installed capacity	3 MW	230 MW	6000 MW
Average turbine size	< 0.5 MW	3 MW	5-6 MW
Average rotor diameter	37 m	98 m	125-130 m
Average water depth	5 m	15 m	>30 m

Table 3.2 Evolution of the offshore wind energy and future trend.

3.2 Offshore wind farms energy transmission system

The key difference between onshore wind farms and offshore wind farms is the different environment of their locations. As a result, offshore wind farms must be provided with submarine cables for the energy transmission.

On the contrary of overhead power cables, subsea power cables have a high capacitive shunt component due to their structure [25]. When a voltage is applied onto a shunt capacitance, capacitive charging currents are generated. These charging currents increase the overall current of the cable reducing the power transfer capability of the cable (which is thermally limited). Therefore, the power transfer capability for a specific cable decreases depending on its shunt capacitance (see section 4.3).

Like the capacitors, the shunt capacitive component of the cables generates more reactive power and charging currents depending on three factors:

- The length (magnitude of the shunt capacitive component).
- The applied voltage.
- The frequency of the applied voltage.

The length is determined by the location of the wind farm and it cannot have big changes. The transmission voltage is directly related to the current and the wind farms rated power. Thus, the main variable which can be changed is the frequency.

Consequently, there are two different types of transmission system configurations: AC and DC. In DC (zero frequency) there are not charging reactive currents, but the energy distribution, the energy consumption and the energy generation is AC voltage.

Therefore, the main drawback of the DC configurations is that they need to transform the energy from AC to DC and vice versa. So, until now, any offshore wind farm with HVDC transmission system has been build. However, a lot of studies are been conducted in this field.

3.2.1 AC Configurations

AC cable systems are a well understood, mature technology. For this reason, all the built wind farms up to now have an AC transmission system to connect the wind turbines to the distribution grid. The distribution grid and the generators are AC, thus, DC/AC converters to transform the evacuated energy are not necessary.

With regards to different types of AC configurations, the different options are divided into two families: HVAC (High Voltage AC) transmission systems and MVAC (Medium Voltage AC) transmission systems.

HVAC transmission system has a local medium voltage wind farm grid (20-30kV) connected to a transformer and a high voltage transmission system. Thus the transmission system requires an offshore platform for the step-up transformer. On the contrary, in MVAC configurations the local medium voltage wind farm grid is used both for connecting all wind turbines and to evacuate the generated power.

As discussed before, AC cables have limited their power transfer capability by the length. But this fact does not mean that wind farms power transfer capability must be limited. If one three-phase connection cannot evacuate the rated power to the required length, is possible to use multiple three-phase connections. For example, Kriegers flak offshore wind farms have planned a transmission system with multiple HVAC connections [26].

On the other hand, for medium voltage configurations (according to [27]), the maximum practical conductor size for operation at 33 kV appears to be 300 mm2, giving a cluster rating in the range of 25 to 30 MW. For wind farms with bigger rated powers more three-phase connections are used. Wind farm is divided into clusters and each cluster is fed by its own, 3 core, cable from shore. At the same voltage level of the wind farms local inter-turbine grid 24-36kV [28].

Therefore, an AC configuration presents multiple design options depending on the transmission voltage level and the number of three-phase connections. In this work, 3 different AC-systems are investigated: HVAC, MVAC and multiple HVAC.

3.2.1.1 High voltage AC transmission HVAC

The first configuration to be discussed is the HVAC. This lay-out is commonly used by large offshore wind farms such as: Barrow - 90MW, Nysted - 158MW or Horns Rev - 160MW.

To transmit the energy produced in the wind turbines to the point where the electric grid is strong enough to absorb it, the HVAC transmission systems follows roughly the same lines for the grid connection scheme. A typical layout for such a scheme is depicted in Figure 3.5.

As shown, the wind turbines are connected to a medium voltage local inter-turbine grid, where the energy of the wind farm is collected to be transmitted to shore, beyond is the transmission system.

The transmission system is made up by: an offshore substation (step-up transformer), submarine cables, the interface between the wind farm and the point of common coupling (substation) and the main grid.

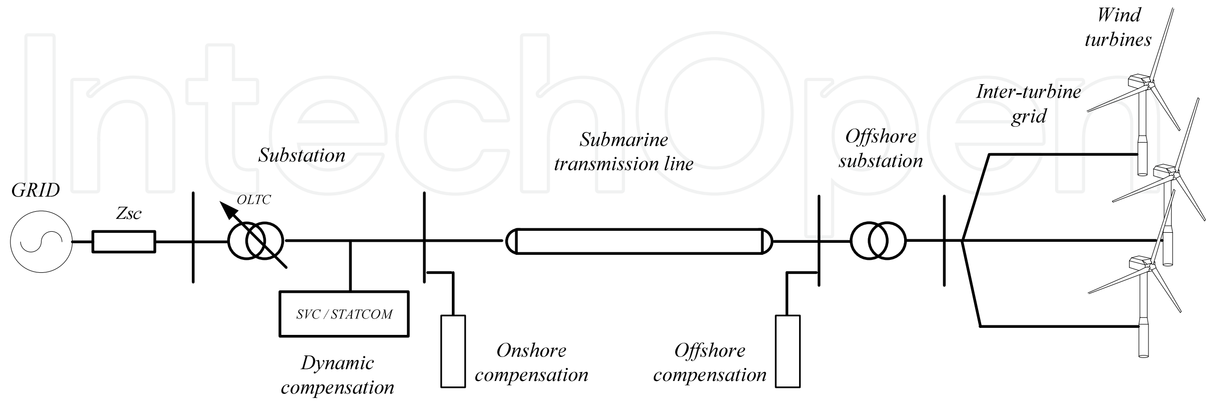


Figure 3.5 Typical layout of HVAC transmission system.

The inter-turbine network is extended from each wind turbine to the collecting point, and due to the fact that it may have a length of kilometers [10], is typically medium voltage 20-36kV (Horns Rev 24kV, Barrow 33kV or Nysted 34kV).

In the collecting point the voltage is increased to the required level in the transmission system (Barrow 132kV, Nysted 132kV, Horns Rev 150kV). The energy is then transmitted from the wind farm to the grid interface (substation) over the transmission system. The substation adapts the voltage, frequency and the reactive power of the transmission system to the voltage level, frequency and reactive power required by the main grid (in the PCC) in order to integrate the energy.

This configuration only has one electric three-phase connection to shore, consequently, if this does not work, the whole offshore wind farm is disconnected.

3.2.1.2 Multiple MVAC

In this configuration the wind farm is divided into smaller clusters and each cluster is connected by its own three-phase cable to shore. This connection is made in medium voltage, at the same voltage level of the wind farms local inter-turbine grid 24-36kV. Therefore, due to the fact that the voltage level of the transmission system and the inter-turbine grid is the same, this electrical configuration avoids the offshore platform (where is placed the step-up transformer) and its cost.

MVAC electrical configurations are used by small wind farms located near to the shore. For example: Middelgrunden (30kV-40MW) at 3Km to shore, Scroby Sands (33kV-60MW) located 2.3Km seaward o North Hoyle (33kV -60MW) at 7-8Km offshore.

The lay-out of the grid connection scheme for an MVAC transmission system is shown in Figure 3.6

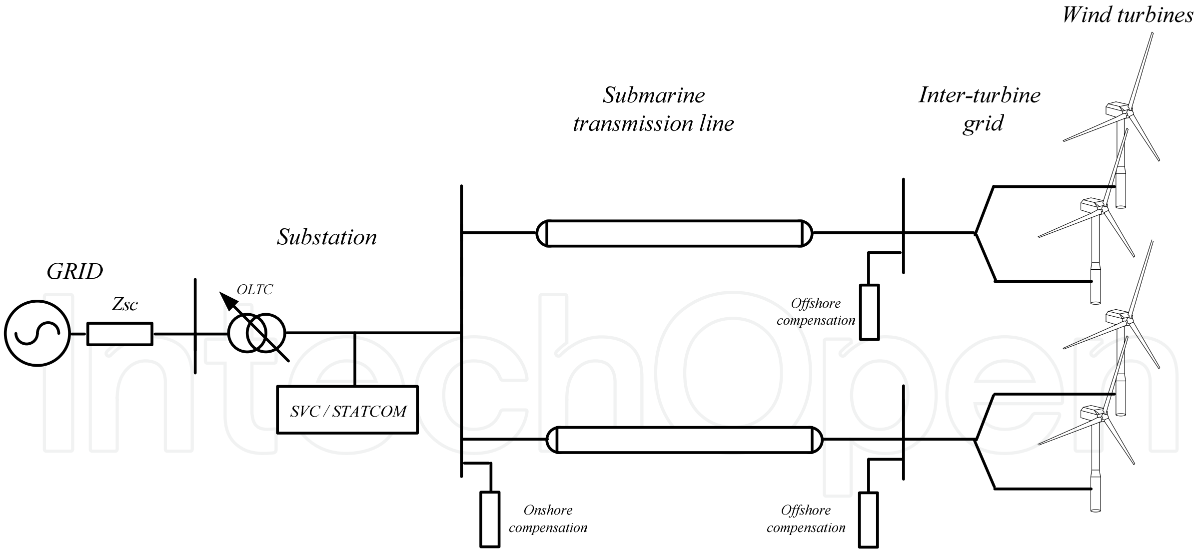


Figure 3.6 Typical layout of multiple MVAC transmission system.

MVAC configuration avoids offshore substantiation and its associated cost, but the energy transmission is through more than one three-phase connection and with lower voltage level than in HVAC configurations. As a result, the energy transmission needs to be made with more current and it is also possible to increase the conduction losses.

As an example, in equations (9)-(14) are compared MVAC configurations conduction losses with HVAC configurations conduction losses for the same cable resistivity and the same transmitted energy (without considering the charging currents due to the capacitive component). The compared cases are 150kV HVAC configuration and a 30kV MVAC configuration with two connections to shore.

$$P = \text{Constant}\ ;\ P_{HVAC} = P\ ;\ 2 \cdot P_{MVAC} = P\ ;\ R_{cable} = \text{Constant} \tag{9}$$

$$V_{HVAC} = 150kV ; V_{MVAC} = 30kV \tag{10}$$

$$V_{HVAC} = 5 \cdot V_{MVAC} \tag{11}$$

$$P = V \cdot I \tag{12}$$

$$I_{MVAC} = \left(\frac{5}{2}\right) \cdot I_{MVAC} \tag{13}$$

$$P_{loss} = I_{active}^{2} \cdot R \tag{14}$$

$$P_{loss\_HVAC} = I_{HVAC}^{2} \cdot R \tag{15}$$

$$P_{loss\_MVAC} = 2 \cdot \left(I_{MVAC}^{2} \cdot R\right) = 2 \cdot \left(\left(\frac{5}{2}\right)^{2} \cdot I_{HVAC}^{2} \cdot R\right) \tag{16}$$

Where: P =Rated power of the offshore wind farm, P_{HVAC} = Rated power of the HVAC three-phase connection, P_{MVAC} = Rated power of each MVAC three-phase connection, V_{HVAC} = HVAC connections voltage level, V_{MVAC} = MVAC connections voltage level, I_{HVAC} = The necessary active current to transmit the rated power of the three-phase HVAC connection at the rated transmission voltage, I_{MVAC} = The necessary active current to transmit the rated power of the three-phase MVAC connection at the rated transmission voltage, P_{loss} = Conduction active power losses, P_{loss_HVAC} = Conduction active power losses for HVAC connection and P_{loss_MVAC} = Conduction active power losses for MVAC connection.

The calculated conduction losses are referring only to the active current, thus to calculate total conduction losses, the conduction losses produced by reactive power (charge/discharge currents) must be taken into account.

MVAC configurations have less voltage (MV) than HVAC configurations (HV), as a result, the reactive power/charging currents generated in submarine cables are lower.

Depending on the transmitted reactive power, the conduction loses increases. Therefore, in cases with big capacitive shunt component of the cable (which depends on the length and cable characteristic) high transmission voltage levels increases significantly reactive currents. Reached such a point where high voltage three-phase connections have more conduction losses than medium voltage three-phase connections

$$\left|I\right| = \sqrt{I_{active}^{2} + I_{reactive}^{2}} \tag{17}$$

In this type of configurations with more than one three-phase connections to shore, if a fault occurs in one of those connections, the faulted clusters can remain connected sharing another connection with other cluster, while the faulty cable is repaired. In this way the reliability of the wind farm is improved.

These redundant connection/s are important when around the location of the wind farm is a lot of marine traffic which can damage submarine cables or if the wind farm location has an extreme climate in winter which makes impossible to repair a cable on this year station [29].

3.2.1.3 Multiple HVAC

This electrical configuration is a combination of the previous two configurations. The wind farm is divided into smaller clusters but these clusters are not connected directly to shore. In this case, each cluster has a collector point and step-up transformer. At this point the voltage is increased to the required level in the transmission system. Typical layout for these configurations is depicted in Figure 3.7.

Offshore wind farms with multiple HVAC transmission systems have large rated power, for example Kriegers Flak (640MW) or Robin Rigg (East/west – 180MW). These wind farms are under construction.

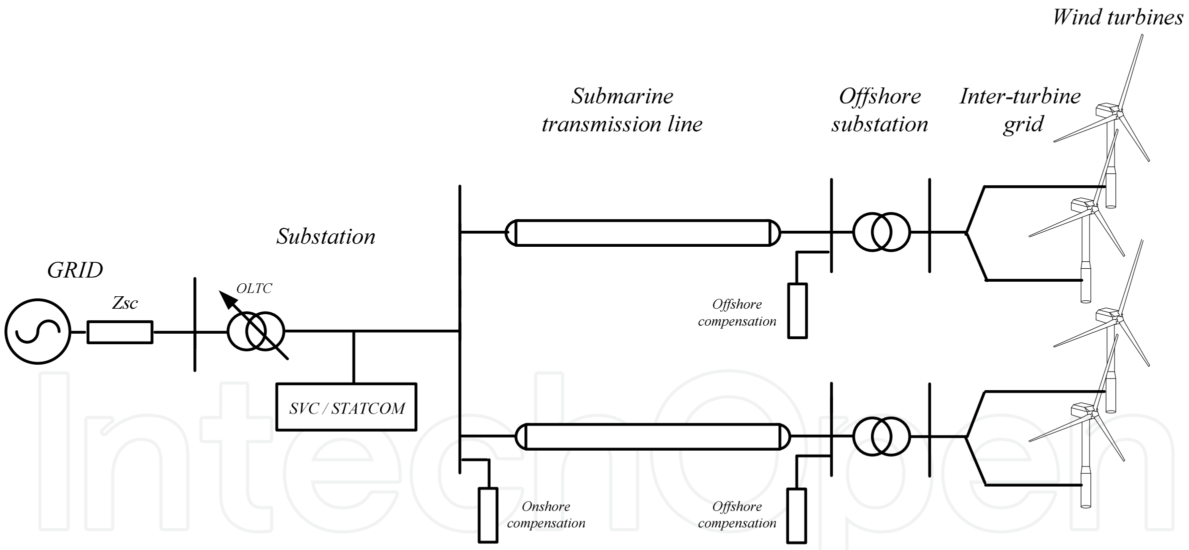


Figure 3.7 Typical layout of multiple HVAC transmission system.

In this electrical configuration, the wind farm is divided into clusters and the rated power of these clusters is a design option. In the same way, the transmitted power through a three-phase connection which depends on the number of clusters can be selected by design also. Moreover, the transmission voltage can be different to the local inter-turbine grids voltage, making possible multiple and different combinations.

In this type of configurations also are more than one three-phase connections to shore. As a result, it is possible to make redundant connections and if a fault occurs in one of those connections, the wind farm does not have to disconnect.

With regards to the drawbacks, this electrical configuration needs several offshore platforms (substations) to increase the voltage to the required level by the transmission system. Another option is place several transformers in the same platform, but the size of the platform increases. Thus, in both cases the cost of the platform increases.

3.2.2 DC Configurations

DC configurations do not generate charging currents or reactive power due to the capacitive shunt component of the submarine cable. This is a huge advantage in comparison with AC configurations, but they also have a big drawback: The distribution grid, the energy consumption and the generators are AC voltages. Therefore these configurations must be provided with AC/DC converters to adequate the voltage to the energy transmission.

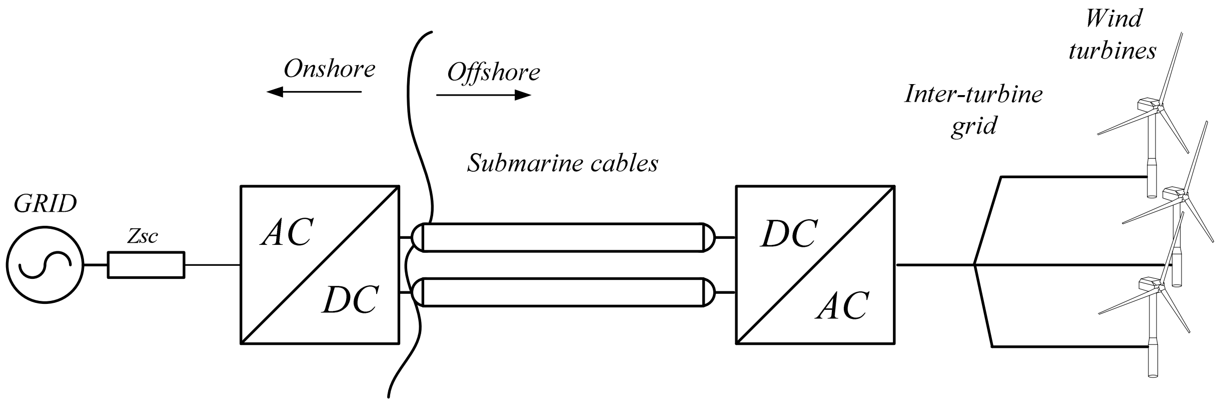


Figure 3.8 Generic layout of bipolar HVDC transmission system.

The AC/DC converters technology and the transmission voltage characteristics are the main features of this kind of configurations:

The transmission can be through mono-polar voltage (Using a single cable) with return to earth or bipolar (Using two cables), Figure 3.8. Due to the extra cable the transmission system can evacuate more power to shore and improve the reliability of the system providing redundancy.

With regards to the AC/DC converters technology, these can be LCC (Line commutated converters) based on thyristors or VSC (Voltage source converter) based on switching devices with the capability to control their turn on and off.

Line Commutated Converter (LCC) devices have been installed in many power transmission systems around the world, so it is a mature technology.

In a line commutated converter, it is possible to control the turn on instant of the thyristor, but the turn off cannot be controlled. Therefore, systems based on this technology for the converters are more susceptible to potential AC grid faults than VSC converters.

In addition, a LCC converter needs a minimum reactive power to work (a minimum current), consequently, this type of converters need voltage on both sides (offshore and onshore) to start working.

Voltage Source Converter (VSC) solution is comparatively new compared to the LCC solution. As the main advantage, the semiconductors switching is decoupled to the grid voltage. Thus, the VSC solutions are able to supply and absorb reactive power to the system independently and may help to support power system stability. As a result, VSCs are suitable for systems with low short circuit power.

In VSC configurations the substation requires fewer components to filter, due to this task can be performed by the converter itself. On the negative side of these converters is their high cost (higher than LCC converters).

3.2.3 AC vs. DC Configurations

To date, any of the built offshore wind farms have a HVDC transmission system, but a lot of studies are been conducted in this field. Furthermore, a small-scale demonstration of HVDC technology is working successfully in Tjaereborg Enge (Denmark). This wind farm has four wind turbines of different types with total rated capacity of 6.5MW.

An AC configuration presents a sort of advantages and disadvantages in comparison with DC configurations. For example, with regard for the energy transmission and integration into the main grid has the following advantages and disadvantages [30]:

- AC configurations do not need to convert all the transmitted energy, due to the generators and the main grids have AC voltage.
- The components for AC configurations are more standard, consequently the cost of the offshore platform is lower.
- AC configurations have well proven and reliable technology. All the built offshore wind farms until now are AC.

In the other hand, the disadvantages for an AC transmission configuration are:

- Long AC cables generate large amounts of reactive power, due to their high capacitive shunt component.
- The associated charging currents to the reactive power reduce the transfer capacity of the cable. This reduction is in proportion to the capacitive shunt component, mainly for the cable length
- All faults in the main power grid affect the collecting AC offshore grid directly and vice versa. So depending on the grid requirements, system may require fast voltage and reactive power control during fault operation.

DC configurations have several features that make them attractive. For example, in these kind of configurations, there are not charging currents. Consequently, the power transfer capability for long cables is not reduced and the reactive power compensation is not needed. As a result, they are more suitable for long distances.

Besides, a DC configuration needs AC/DC converters at both ends of the line. Thus, the transmission system has the capability to control both the voltage and the power injected to the main grid.

These converters provide also electrical decoupling between the collecting AC offshore grid and the main power grid for faults in the main power grid.

On the other hand, there are several disadvantages associated to this technology, mainly the cost:

- These configurations have higher substation cost, both offshore and onshore.
- Higher overall losses (switching losses in power converters)
- Limited offshore experience with VSC-transmission systems
- It is possible to increase the injected harmonic level to the main grid, especially with LCC technology [31], [32].

The advantages and disadvantages of each transmission configuration can be seen summarized in Table 3.3

AC	**DC**	
	LCC	**VSC**
Is possible to avoid offshore platform.	Needs an offshore platform.	Needs an offshore platform.
Is possible to avoid switching losses (to avoid converters).	Switching losses at AC/DC converters.	Switching losses at AC/DC converters.
Need reactive power compensation	Not need reactive power compensation.	Not need reactive power compensation.
All faults in the main power grid affect the collecting AC offshore grid directly and vice versa	Electrical decoupling between the collecting AC offshore grid and the main power grid.	Electrical decoupling between the collecting AC offshore grid and the main power grid.
charging currents reduces the power transfer capacity	There are not charging currents	There are not charging currents
Power transmission capability in both directions.	To change the direction of the power flow need to change the polarity.	Power transmission capability in both directions.
Mature and reliable technology in offshore applications.	Well proven technology but in other applications.	Well proven technology but in other applications.
Less cost due to the standard components	Needs a minimum reactive power to work. Also in no-wind conditions	High cost.

Table 3.3 Comparison of AC and DC transmission systems.

3.2.4 The optimum layout depending on rated power and distance

Several studies about which transmission configuration is the optimum depending on the distance to shore and rated power are been analyzed in this chapter [33], [34] and [35].

In [36] the analysis is focused on HVAC and HVDC configurations with pretty high rated powers (until 900MW) and long distances to shore (up to 300 Km). As a conclusion, this survey determine AC technology like the optimum for offshore wind farms with rated powers until 200MW and distances to shore shorter than 100 Km.

However, the survey does not determine the optimum technology in the range between 200MW-400MW with distances to shore between 100Km-250Km. As says in the report AC technology is losing attractiveness increasing the distance to shore. So DC configurations are the optimum option for big power and long distances.

A similar study is presented in [27], which determines the limits of each technology for the transmission system of offshore wind farms as follows: Until 100MW and 100Km to shore the optimum configuration is MVAC, between 100MW-300MW and 100Km-250Km the optimum is HVAC and for bigger rated powers and longer distances HVDC.

Finally in [37], the report places the limits of each technology as follows: The distance limit for using AC transmission configuration is between 80 and 120 km, if the reactive power generated in submarine cables is compensate at both ends. But if the transmission system has a reactive power compensator in the middle of the submarine cable besides the reactive power compensators at the both ends, AC technology may be the optimum until to 180 km. This report considered these limits flexible.

The summarize of the previous studies is shown in Figure 3.9, in this picture are depicted the areas where each type of transmission is the optimum configuration (white) and the areas where depending on the characteristics of each wind farm can be any of them the optimum configuration (striped area).

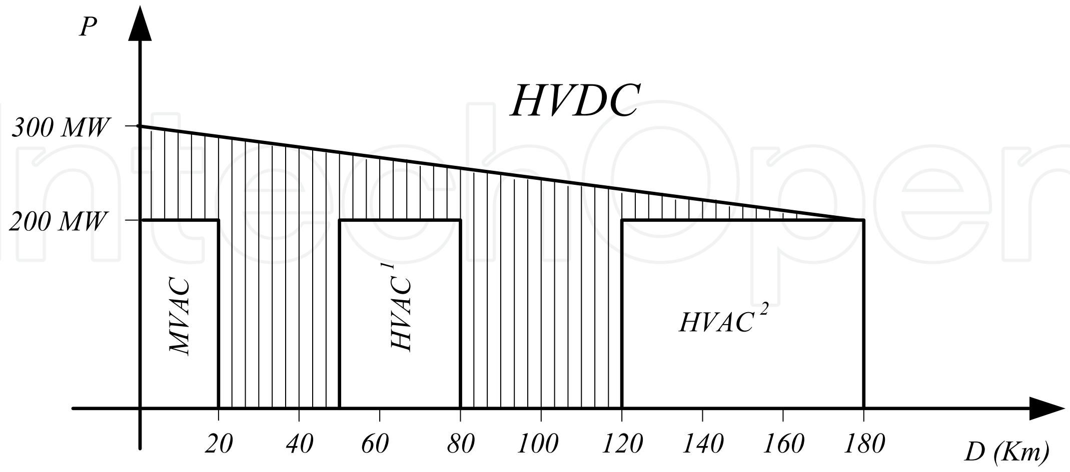


Figure 3.9 Optimum configuration depending on distance to shore and rated power: (1) With reactive compensation at both ends, (2) With reactive compensation at both ends and another one in the middle of the submarine cable.

3.3 Offshore wind farms electrical collector system

The local inter-turbine grid can be AC or DC, although this characteristic does not determinate the transmission systems technology. The transmission system can be made with the same technology or not. To date all the inter-turbine grids are AC and a lot of studies of HVDC transmission systems have AC inter-turbine grids. Thus, in the present book, only AC collector grids are considered.

The design of the wind farms collector system begins with the selection of the inter-turbine cable and inter-turbine grids (collection grid) voltage level. The use of voltage levels above 36kV for the inter-turbine grid becomes uneconomic. Due to the impossibility to accommodate switchgear and transformers in each turbine tower, so 33-36kV is widely used for collection schemes [38].

The number of turbines connected to the same cable and the rated power of these wind turbines with the voltage level determines the inter-turbines cable section. This aspect is not trivial, as cables have to be landed on seabed, and a larger section means a larger bending radius (higher stiffness), with consequent difficult maneuvering of cable posing ships and larger mechanical protection components [39].

With regards to the spatial disposition of the wind turbines inside the inter-turbine grid, most offshore wind farms to date, have had simple geometric boundaries and have adopted a straightforward rectangular or rhomboid grid [38].

The cable length between two wind turbines is determined mainly for the aerodynamic efficiency of each turbine. Due to the length between two wind turbines must be enough to avoid turbulences generated at the turbines around it. According to [40] the length between two wind turbines is in the range of 500-1000 m.

In onshore wind farms, the electrical system configuration is usually decided by the turbine and substation positions, and the site track routes. Offshore, on the contrary, to design the inter-turbine grid is more freedom, and at first sight is not clear how to choose from the wide range of possible options [41].

Nevertheless, for wind farm collector systems employed in existing offshore wind farms are various standard arrangements. In this way, four basic designs are identified [40], [34]:

- Radial design.
- Single side radial design.
- Double-sided radial design.
- Star design.

3.3.1 Radial design

The most straightforward arrangement of the collector system in a wind farm is a radial design. The wind turbines are connected to a single cable feeder within a string. This design is simple to control and also inexpensive because the total cable length is the smallest to connect all the wind turbines with the collecting point [41]

The radial design is not provided by redundant connections. Consequently if a fault occurs in a cable or at the hub, the entire radial string collapses and all of the wind turbines in the string are disconnected.

The maximum number of wind turbines on each string is determined by the rated power of the generators and the rated power of the submarine cable. The lay-out of this kind of collector systems is shown in Figure 3.10.

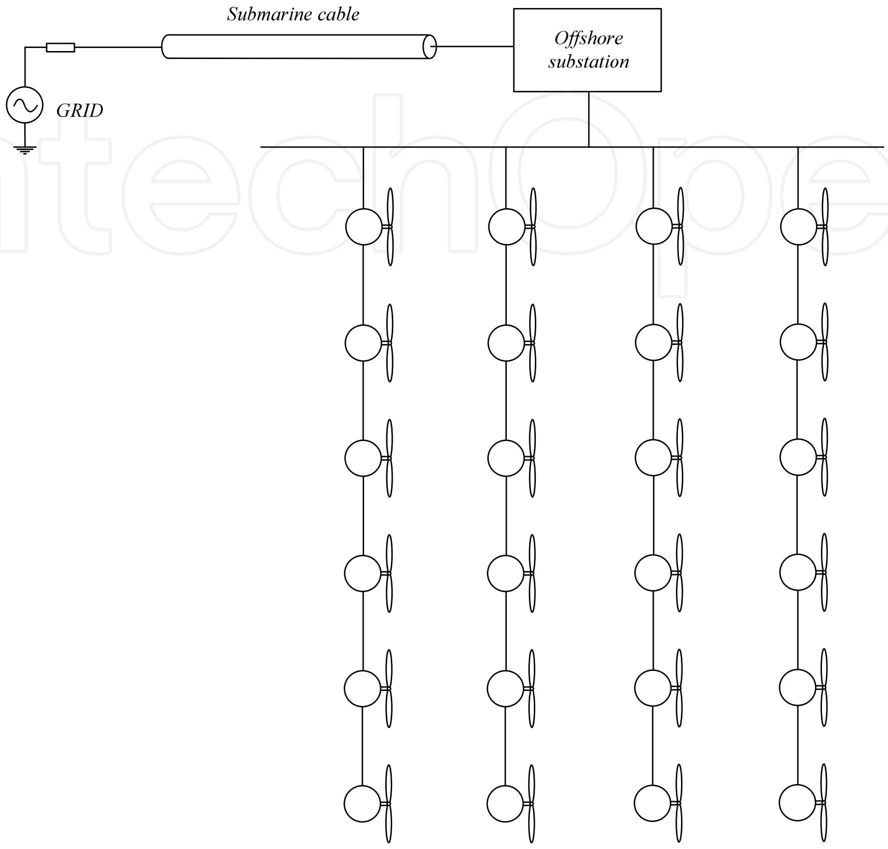


Figure 3.10 Layout of the radial design for local inter-turbine grid.

3.3.2 Single-sided ring design

A single-sided ring design is similar to radial design, but with an extra connection. The additional cable connects the last wind turbine with the collector.

In comparison with radial inter-turbine grid design, the additional cable incorporates a redundant path to improve the reliability of the system. Therefore, this additional cable must be able to evacuate all the energy generated in the string.

The main drawback of this lay-out is the required cable length, longer than in the radial design with its associated cost increase.

To justify the use of redundancy in the collecting system, it is considered the energy that will be saved with this redundant cable during its useful life (usually 20 years) and this benefit is confronted with the cost of redundant cable. In this way, In [41] is reported that the most internal power networks of existing offshore wind farms have very little redundancy or none at all.

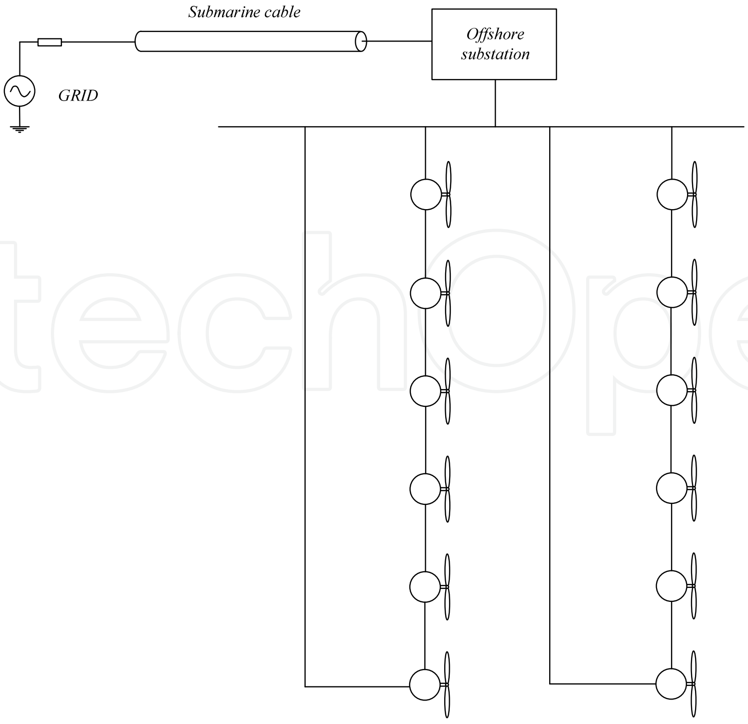


Figure 3.11 Layout of the single sided ring design for local inter-turbine grid.

3.3.3 Double-sided ring design

A double-sided design is similar to single-sided ring design but in this case the extra connection is between the last wind turbines of two strings, as is illustrated in Figure 3.12

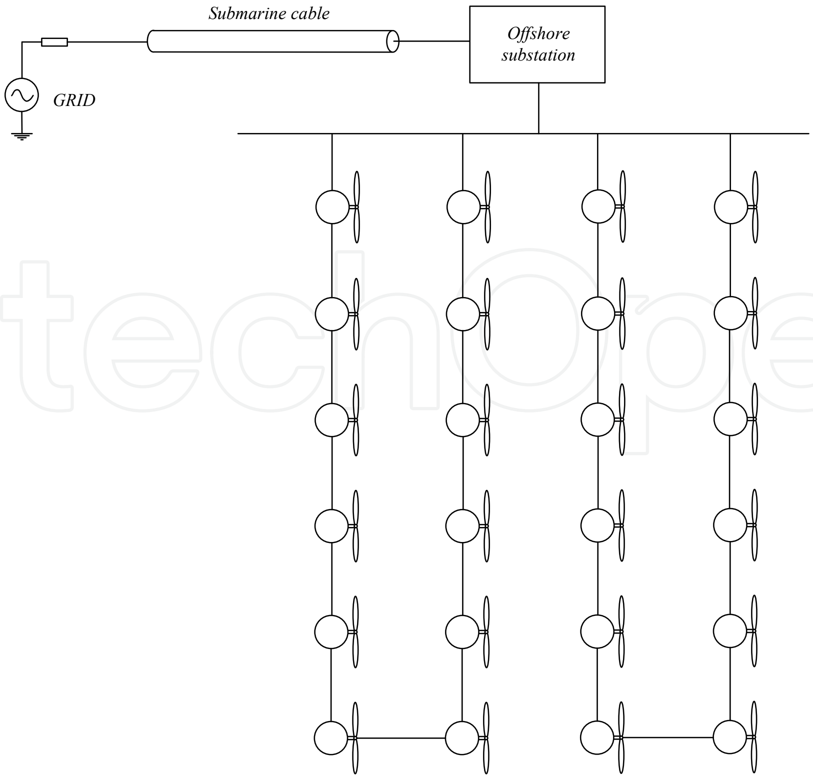


Figure 3.12 Layout of the double sided ring design for local inter-turbine grid.

Connecting the last wind turbines of each string saves cable length, but in the other side, if a fault occurs, the whole output power of two strings is deviated through the same cable. Thus, the inter-turbine cable has to be sized for that purpose.

3.3.4 Star design

The star design has a large number of connections, because each turbine is connected directly to the collector point in the center. So this design provides a high level security for the wind farm as a whole. If one cable have a fault, only affects to one turbine (the turbine connected trough this cable).

The additional expense in longer subsea cables is compensated at least in part with less cable sections required by this design. Due to the fact that trough the inter-turbine cable is only transmitted the energy generated by one wind turbine. So the biggest cost implication of this arrangement is the more complex switchgear requirement at the wind turbine in the centre of the star.

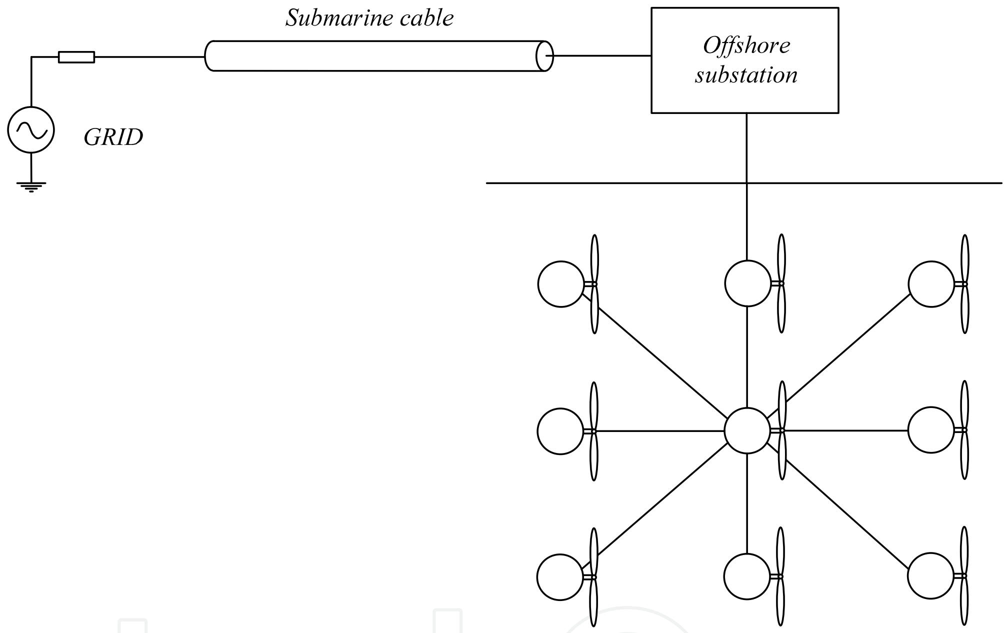


Figure 3.13 Layout of the star design for local inter-turbine grid.

3.4 Chapter conclusions

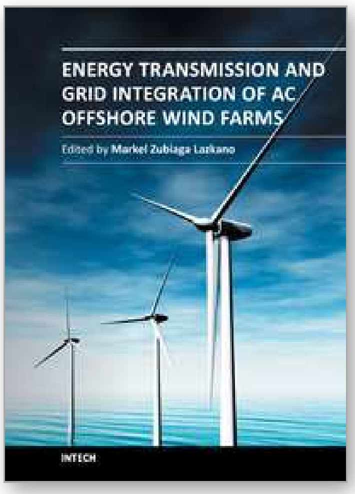
Due to the fact that the energy distribution grid, the energy consumption and the energy generation are AC voltages, all the built offshore wind farms to date have AC transmission system. So, AC alternative is well proven and feasible.

AC and DC configurations have their advantages and disadvantages. All the considered studies in this chapter are agreed that for long-distances to shore DC option would be the optimum if not the only viable. But at present DC transmission options are proposals to adapt the technology to the offshore environment.

The analyzed studies are not agreed about the limits on distance and the rated power for the optimal transmission option (AC or DC). These studies neither are agreed about within each family which transmission configuration (HVAC, MVAC or Multiple HVAC) is the optimum.

In general, the studies are agreed in rough lines. Highlighting that for short distances to shore and low rated power the optimum option is AC and for long distances to shore and big rated power DC. Consequently, depending on the rated power of the wind farm and its features any transmission option (AC or DC) can be the optimum.

Therefore, it is necessary a more detailed analysis, which takes into account features of specific cases in order to define the optimum transmission option and configuration for each offshore wind farm.



Energy Transmission and Grid Integration of AC Offshore Wind Farms
Edited by MSc Markel Zubiaga

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This book analyses the key issues of the offshore wind farm's energy transmission and grid integration infrastructure. But, for this purpose, there are not evaluated all the electric configurations. In the present book is deeply evaluated a representative case. This representative case is built starting from three generic characteristics of an offshore wind farm: the rated power, the distance to shore and the average wind speed of the location. Thus, after a brief description of concepts related to wind power and several subsea cable modeling options, an offshore wind farm is modeled and its parameters defined to use as a base case. Upon this base case, several analyses of the key aspects of the connection infrastructure are performed. The first aspect to analyze is the management of the reactive power flowing through the submarine cable. Then, the undesired harmonic amplifications in the offshore wind farms due to the resonances and after this, transient over-voltage problems in the electric infrastructure are characterized. Finally, an offshore wind farm connection infrastructure is proposed in order to achieve the grid code requirements for a specific system operator, but not as a close solution, as a result of a methodology based on analyses and simulations to define the most suitable layout depending on the size and location of each offshore wind farm.

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INTECH
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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821