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Substations for offshore wind farms: a review from the perspective of the needs of the Polish wind energy sector

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Abstract. Offshore renewable energy, and in particular the offshore wind energy sector, is still developing in many countries around the world. Wind offshore projects are characterized by the need to build offshore electric power transmission infrastructure. Offshore substations are a key element of submarine electric power transmission systems. Due to the environmental conditions, an offshore substation is constructed as an indoor facility located on a platform. Depending on the offshore wind farm capacity, there are various solutions for platform and substructure designs used for the substation. Numerous economic and technical analyses indicate a significant potential for the development of offshore wind energy in Poland. By 2030, this potential is set at 6 GW of installed capacity, taking into account 2.2 GW of power included in the connection agreements being concluded. The main objective of this paper is to present the prospects for the development of offshore wind energy in Poland, and to describe the various offshore substation solutions and the different aspects of substation operation. Offshore wind energy resources and power capacity are also presented. Moreover, solutions for offshore substation platforms, electrical equipment and layout, functions of offshore substations in the power systems and offshore substation designs are described.

Key words: offshore substation, offshore wind energy, Poland, offshore wind farm, offshore grid.

1. Introduction

In late 20th century, strong development of the wind power sector increased the focus of the power industry on offshore technologies. The first offshore wind farm (OWF) was installed in Denmark in 1991 [1]. During the early stages of the development of offshore wind farms (OWFs), due to the low installed capacity and small transmission distance to the onshore grid, offshore substations (OSs) were not required. Currently, there has been a trend in wind power engineering to combine multiple wind generation units (wind turbines), each with the capacity of many megawatts, and to connect them together to the onshore grid. This way, the total capacity of an OWF can be more than several hundred megawatts [2–4]. In addition, OWFs that are currently under construction or whose construction is planned, are relatively far away from the onshore grid and thus require an offshore substation (OS) which is installed on a special platform.

Specific environmental conditions in which the OSs operate require, in addition to proper OS electric systems, adequate design of the platform structure housing the OS. In general, analyses are required to select the optimum platform structure, taking into account offshore conditions and the role of the OSs in the power system [5].

The development of offshore technologies has triggered an extensive use of marine areas to tap power sources [6, 7]. As a result, the European and global community have been taking numerous initiatives to develop offshore wind energy [8–12]. Recently, OWFs and offshore grids have distinctly expanded worldwide [13–16]. According to WindEurope's Central Scenario, 323 GW of cumulative wind energy capacity would be installed in the European Union (EU) by 2030, including 253 GW onshore and 70 GW offshore [17].

In the Baltic Sea basin, Poland has been active in OWF development [18, 19] as prospects for the Polish wind power sector increase. In the EU, Poland has topped the charts with the level of capital to be invested in renewable energy sources [17]. Currently, 2,936 renewable energy sites with total capacity of 8.5 GW operate in Poland [20]. The percentage for individual sources is shown in Fig. 1.

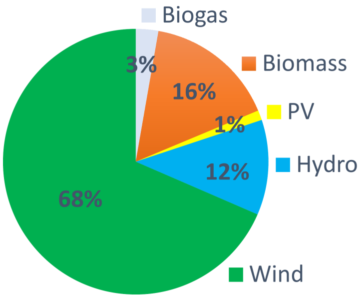

Fig. 1. Renewable energy sources in Poland

Offshore power systems exporting energy from offshore areas to the onshore grid can be implemented in a variety of ways [21], using alternating current (AC) or direct current (DC) [18, 22] technologies. These systems must meet various requirements stipulated by transmission system operators [23]. In practice, in each feasible option, offshore grids require the construction of OSs [24–29] that play a key role in the power transmission and distribution process.

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This paper presents an overview of OS-related topics as key part of OWF and offshore grids. The review is complemented by the presentation of prospects for the development of offshore wind energy in Poland. This paper has been inspired by the authors' participation in research work on Polish OWFs and offshore grid [30].

This text is divided into eight sections. Section 1 forms an introduction. Section 2 presents offshore wind energy in Europe, with particular focus on the Baltic Sea area. Section 3 discusses the potential for offshore wind energy in Poland and the contemplated OWF projects. Section 4 contains an overview of solutions for platforms on which to install OSs. Sections 5 and 6 present topics regarding the electric equipment of OSs and the role of OSs in the power system. Section 7 addresses topics related to OS design. Section 8 discusses the key findings of the paper.

2. Offshore energy in Europe and the Baltic Sea area

At the end of 2016, the total capacity of wind turbines in offshore areas worldwide was 14.384 GW [31]. Currently, most OWFs are situated in Europe. Total capacity of European OWFs is 12.631 GW, which makes up 88% of global OWF capacity. The remaining 12% are OWFs situated in China, Japan, South Korea and the US [31]. In Europe, OWFs are situated in the Irish Sea (2.689 GW), North Sea (9.099 GW) and Baltic Sea (1.457 GW) areas. In Europe, the following countries stand out in terms of offshore wind energy: United Kingdom (5.156 GW), Germany (4.108 GW), Denmark (1.271 GW) and the Netherlands (1.118 GW) [31]. The most recent OWF development projects in Europe involve capacities around 3 GW [31–33].

A total of 19 OWFs, with combined capacity of almost 1.5 GW, have been developed in the Baltic Sea area. The highest numbers of OWFs have been implemented in Denmark in south-western Baltic Sea [34]. It is worth noting that OWF projects in the Baltic Sea are expanding year by year, and their combined installed power will grow. In 2017, Finland launched OWF Tahkoluoto with total capacity of 42 MW [35]. Table 1 presents an overview of OWFs built in the Baltic Sea area [36].

3. Offshore wind energy sources in Poland

3.1. Physical oceanography of the Baltic Sea. The Baltic Sea is an intra-continental semi-enclosed sea in the northern part of Europe, with an area of about 370,000 km^2 and volume of about 21,000 km^3. The maximum depth is 459 m (Landsort Deep). Mean depth is 56 m, but roughly 17% of the area is shallower than 10 m [37]. The Baltic Sea is a semi-enclosed brackish basin that has very small tidal amplitudes and is rather well protected from Atlantic storm surges [38]. The Baltic Sea is surrounded by nine European countries and known as a marine area highly exposed to human impact [39]. The salinity of the Baltic Sea ranges from 2 to 12‰, therefore it is referred to as a semi-salty sea [40].

Marine areas of Poland consist of internal waters (a part of the Gulf of Gdańsk with Puck Bay, Puck Lagoon, and the Vistula Lagoon, as well as the Szczecin Lagoon), the 12-nautical-mile-wide territorial sea, and the Exclusive Economic Zone [41]. There are 843 km of coastline within the borders of Poland. The seabed along the Polish shore is diverse. The depth of the Polish part of the Baltic Sea ranges from 10 to 100 m.

Table 1
Existing OWFs in the Baltic Sea area [36]

Name	Country	Commissioning year	Depth range [m]	Distance from shore [km]	Capacity [MW]
Tahkoluoto	Finland	2017	8–15	9.8	42
EnBW Baltic 2	Germany	2015	23–44	32	288
Anholt	Denmark	2013	15	20	399.6
Karehamn	Sweden	2013	21	5	48
EnBW Baltic 1	Germany	2011	16–19	16	48.3
Rødsand 2	Denmark	2010	6–12	9	207
Sprogø	Denmark	2009	6–16	10	21
Avedøre Holme	Denmark	2009	2	0.5	10.8
Lillgrund	Sweden	2008	4–13	9	110.4
Kemi Ajos	Finland	2008	1–7	3	30
Rødsand 1	Denmark	2003	6–9	11	165.6
Samsø	Denmark	2003	10–13	4	23
Frederikshavn	Denmark	2003	1–4	0.3	7.6
Yttre Stengrund	Sweden	2001	6–8	2–4	10
Middelgrunden	Denmark	2000	3–6	4.7	40
Utgrunden	Sweden	2000	6–15	4–7	10.5
Bockstigen	Sweden	1998	5–6	4–6	2.75
Tunø Knob	Denmark	1995	3–7	6	5
Vindeby	Denmark	1991	2–4	1.8	4.95

3.2. Poland's offshore wind energy potential. Global and European concern about energy and environmental resources made the growth of renewable energy sources (RESs) an important part of the European energy policies [42]. EU countries have already agreed on a new renewable energy target of at least 27% of final energy consumption in the EU as a whole by 2030 as part of the EU's energy and climate goals for 2030 [43].

Poland has good wind conditions and a long tradition of harnessing wind power for economic purposes [44]. For Poland, both the existing document of the Ministry of Economy, i.e. the Energy Policy of Poland 2030 [45], and the Energy Policy of Poland 2050, currently under development, both resulting from the agreement of the European Council regarding the 2030 climate and energy framework, provide for a significant share of energy from renewable sources [46]. Table 2 presents the potential for offshore wind energy in Poland. It also shows that there is feasible potential to build wind power sources with combined capacity of 7.5 GW.

Table 2
Potential for offshore wind energy in Poland [47]

Potentia type	Capacity [GW]	Energy production [TWh]
Theoretical potential	130	380
Technical potential	130	380
Technical capacity with environmental considerations	20	60
Economic potential	7.5	22.5

Figure 2 presents the distribution of average annual wind speed in Poland's coastline areas [48]. Due to Polish laws, for the protection of the sea shore, wind farms need to be built beyond the territorial sea, or at least 15 kilometers off shore. The map presented in Fig. 2 shows that average annual wind speed in this area is about 8 m/s [48].

Based on environmental analyses, four suitable locations for the construction of offshore wind farms have been selected in the Polish offshore economic zone [44, 49]:

- Słupsk Bank,
- Southern Middle Bank,
- area of Kołobrzeg,
- Odra Bank.

Figure 3 shows the rough division of areas suitable for locating OWFs in them. In addition, potential sites of power export from OWFs to the onshore grid (Grzybowo, Ustka and Lubiatowo) are marked.

According to data collected by the Polish power regulator (Energy Regulatory Office), the wind source capacity in Poland at the end of 2017 was 5.824 GW [20]. Despite conditions favorable for the development of wind power, no OWF has been built in the Polish coastal area yet. However, work is in progress on several OWF projects.

Table 3 shows a list of Polish OWF projects. The most advanced design work is currently carried out for two OWFs: Middle Baltic III and Baltica 3. Due to high capacities and long transmission distance to the onshore grid, these OWFs will need OSs to operate.

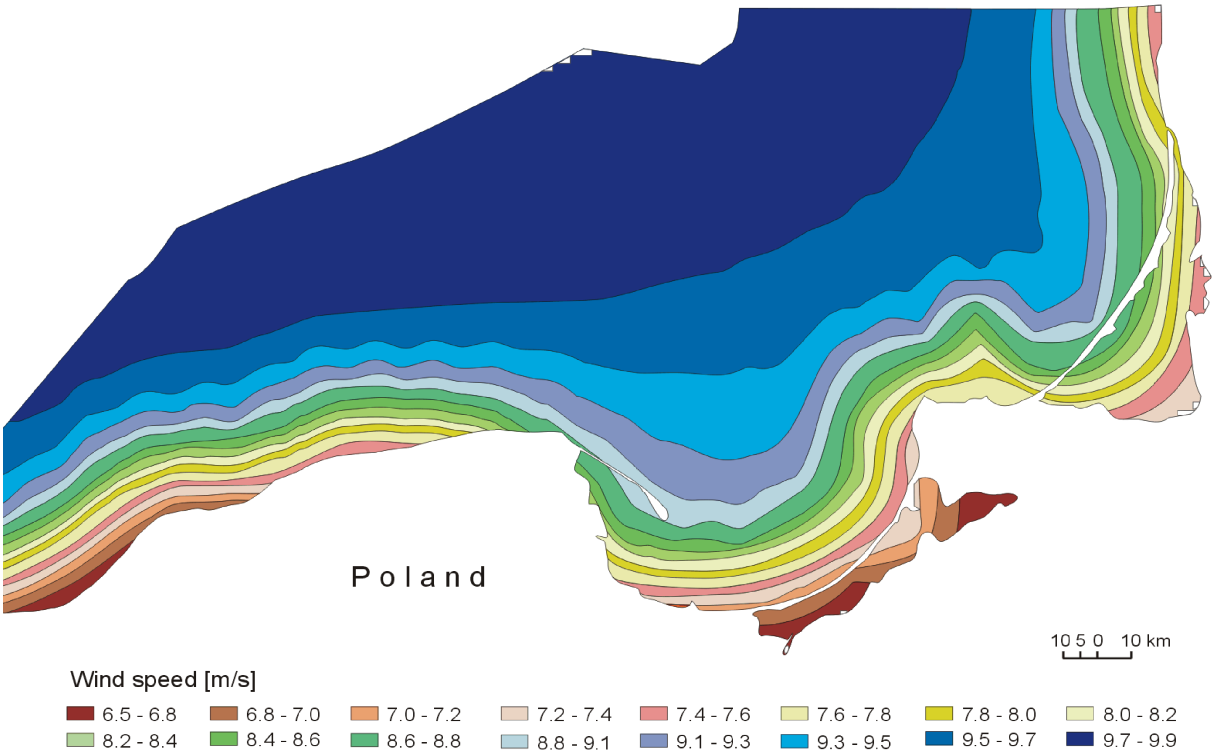

Fig. 2. Average annual wind speed in the coastal area, (based on [48])

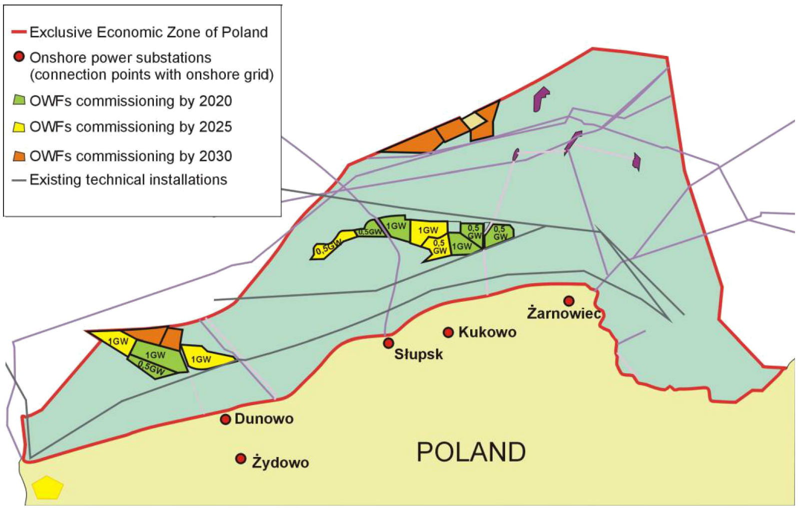

Fig. 3. Contemplated OWFs locations along the Polish coastline (based on [49])

Table 3
Characteristics of currently contemplated Polish OWFs [36]

Name	Capacity [MW]	Average wind speed [m/s]	Depth range [m]	Distance from shore [km]	Location
Bałtyk Środkowy I	600	8.88	32–48	44	Southern Middle Bank
Bałtyk Środkowy II	600	8.97	23–34	37	Słupsk Ban
Bałtyk Środkowy II	600	8.99	25–34	23	Słupsk Ban
Baltica	1,202.5	9.09	15–42	86	Southern Middle Bank
Baltica	1,202	8.97	22–52	39	Słupsk Ban
Baltica	1,045.5	9.02	33–39	33	Słupsk Ban
Bałtyk Północny – Phase 1	1,140	9.07	20–32	81	Southern Middle Bank
Bałtyk Północny – Phase 2	420	9.09	20–30	81	Southern Middle Bank

The planned construction of OWFs in Poland also involves the need to expand the offshore transmission network. Due to the connection of generating sources, transmission network development planning can be implemented in various time horizons [50]. However, a proper planning process requires a series of analyses and checking technical criteria [51, 52]. Offshore grid development requires capital spending to build submarine cable lines and OSs. Figure 4 presents a concept design of offshore grid development necessitated by the connection of OWFs and implementation of offshore interconnections. Schematic location of OWFs has been marked with red rectangles (A, B, C). Blue dots show the location of OSs.

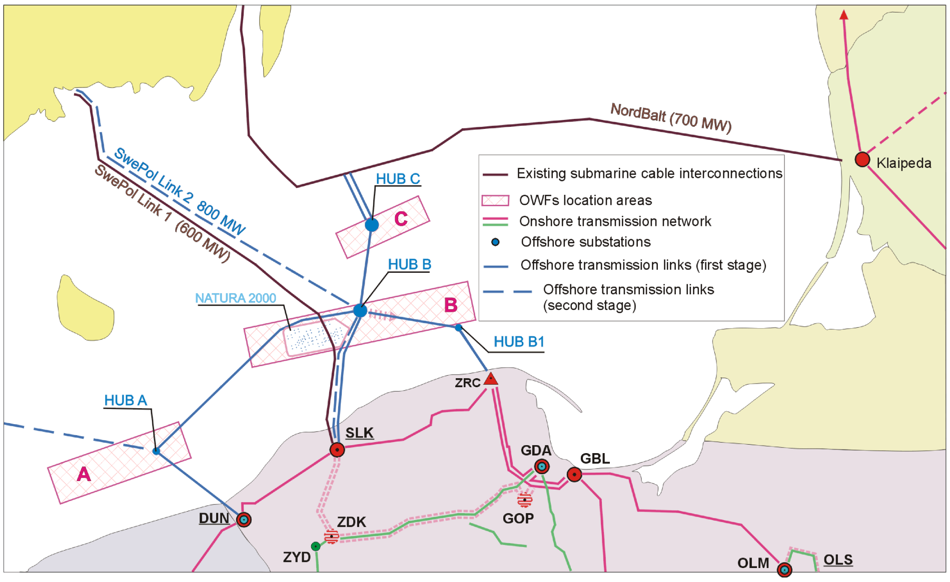

Fig. 4. Offshore grid development for the purpose of OWFs (based on [53])

4. Offshore substation platform

4.1. Offshore substation as part of offshore grid. An offshore wind farm is typically composed of four main parts, namely wind turbines (WT), the inner grid (IG), offshore substation and external grid (EG) [54]. The inner grid operates at medium voltages and a substation steps the voltage up to the transmission voltage [55]. The offshore substation receives power from wind turbines and exports it to the grid. On the next stage of offshore grid development there is an offshore substation that receives power from several offshore wind farms and performs the multi-connector function.

Due to environmental conditions, offshore substations are implemented as indoor structures on platforms anchored to the seabed. Substation platforms are designed like oil platforms but the structure has some specific solutions. The platform is designed to accommodate the main and grounding transformers, the switchgear and other assorted accessories [56], which are described later in this paper.

4.2. Offshore substation platform structure. The structure of the substation platform can be divided into two main parts (Fig. 5):

- Support structure, which includes the foundation structure and substructure, with the main purpose of transferring the loads from the topside and support structure to the seabed [57].
- Topside, which is typically a box-shaped structure placed on top of the substructure that contains electrical equipment such as transformers, high voltage (HV) and *medium* voltage (MV) switchgear, etc. [58].

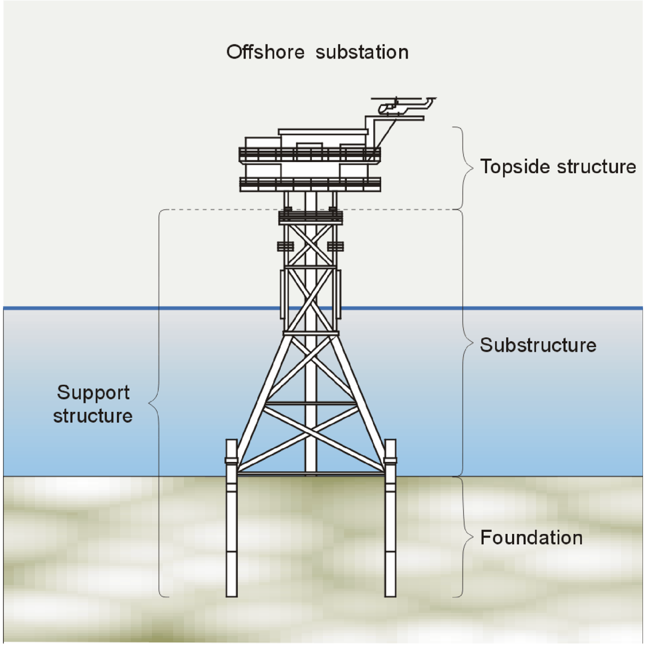

Fig. 5. Typical offshore substation structure

4.3. Support structure. Depending on seabed structure, two types of offshore platforms can be distinguished:

1. bottom founded (or fixed) platforms,
2. floating platforms.

In the Polish Baltic Sea area, fixed platforms are considered for offshore power engineering, hence the subsequent part of this paper will focus on this type of platforms. Figure 6 shows the types of support structures for bottom founded platforms.

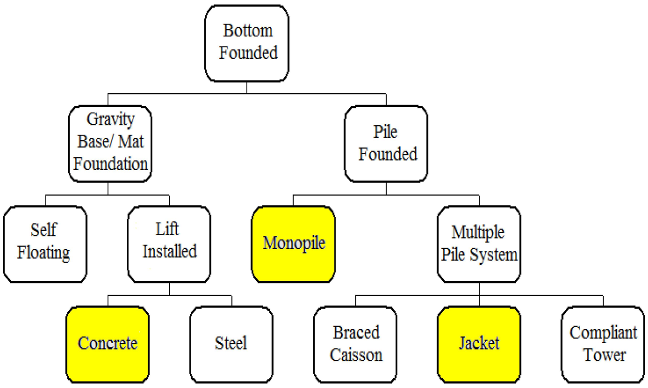

Fig. 6. Types of support structures for bottom founded platforms

Within the support structures shown in Fig. 6, OSs usually use: gravity-based (concrete), monopile and jacket structures. Table 4 presents a list of selected support structure properties, and Fig. 7 shows the main parts of selected support structures.

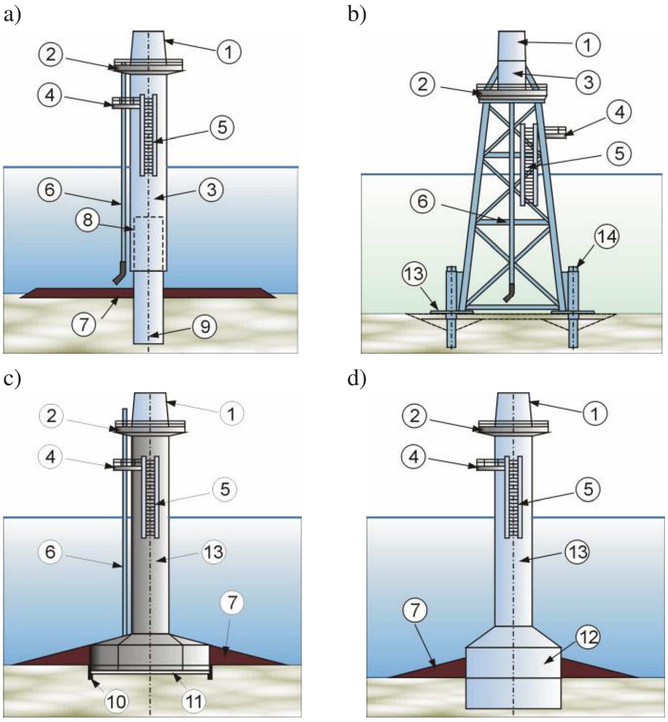

Fig. 7. Main components of offshore support structures: a) monopile; b) jacket; c) gravity base; d) suction bucket (1 – tower, 2 – work platform, 3 – transition, 4 – intermediate platform, 5 – boat landing, 6 – external J tubes, 7 – scour protection, 8 – grouted connection, 9 – monopile, 10 – skirt, 11 – concrete layer, 12 – suction bucket, 13 – shaft, 14 – pile sleeve, 15 – mud mat)

Table 4
Comparison of support structure types [57, 59, 60]

Factor	Gravity		Monopile	Multiple pile			Self-elevation
	Concrete	Steel		Braced (gravity) caisson	Jacket	Compliant tower	
Fabrication	Simple	None used*	Simple	Complex	Complex	Complex	Complex
Vibration issue	No	None used*	Yes	No	No		Yes
Maximum water depth	(2–30) m	None used*	(2–30) m	(2–30) m	(2–60) m	(100–300) m	<50 m
Wind park interface	Medium		Medium/poor	Good	Good		Medium/good
Life extension	No		No	Not on bottom	Yes		No
Soil requirements	Yes – hard soil		No	Yes – hard soil	No		No
Topside weight	<2,000 tons		<1,200 tons	Inst. range limit	<4,000 tons		<4,000 tons
Maximum height above LAT	40 m				30 m		
CAPEX**	1		1	3	3		3
OPEX**	1		2	3	3		4
Advantages	Small amount of steel. There is no fixation to the ground	None used*	Low collision	No fastening to the ground. Easy to remove	Variety of application	Application at large depths	
Disadvantages	Expensive in the case of large depth	None used*	Requires heavy hammer	Little experience with this solution	Requires large amounts of steel	Requires large amounts of steel	

* Application for small test solutions (theoretical solution, not used practically).

** Economic assessment is given by a number between 1 and 5 – 1 is lowest budget and 5 is highest.

One variety of multipile platforms is a jack-up platform, also called self-elevation platform. Jack-up platforms can be hoisted up above the sea level by lowering their poles. The platform structure can stay afloat, which makes it possible to easily move the platform, after raising its poles, to the installation place. High mobility and stability of jack-up platforms make them an attractive solution for the construction of OSs.

4.4. Topside. The topside is typically a box-shaped structure placed on top of the substructure that contains the electrical equipment included in the offshore substation, providing for some or all of the platform's functions [57, 60, 61].

The topside layout is mainly determined by:

1. Electrical substation layout.
   This layout results from the type of the power substation implemented in the offshore grid, the capacity of the offshore wind farm and electrical parameters (voltage, type of current (AC or DC) of the submarine transmission system). Topsides for high voltage DC (HVDC) substations are generally larger than their high voltage AC (HVAC) counterparts.
2. Additional requirements, which include:
   - the operating conditions of electrical equipment (cooling systems, isolating clearances, etc.);
   - the working conditions for the substation's services or personnel (personnel rooms, air conditioning, accommodation, etc.).
   - safety, navigational, signaling and rescue systems (fire systems, lightning systems, evacuation, etc.);
3. Adopted solution for the support structure [62].

Other factors that can impact the topside structure are topside port requirements due to the fact that the topside structure is made onshore and then transported to the installation location. The topside is composed of decks divided into rooms and halls with the lowest deck being the cable deck, whereas the topmost deck accommodates signaling equipment and a helipad (if present in design). Electrical equipment on OS offshore platforms is arranged in either of the following two ways:

- vertical placement of equipment – used mainly in substations for OWFs with low capacities of up to 100 MW, where the support structure is gravity-based or monopile;
- horizontal placement of equipment – used in substations for OWFs with high capacity in excess of 100 MW, where – due to the quantity and weight of substation elements, a jacket multi-pile support structure is necessary.

5. Electrical equipment

Electrical equipment of the offshore substation depends on the type of electrical current (AC – Alternating Current, or DC – Direct Current) used for the transmission of electrical energy. Due to the type of electrical current used, HVAC and HVDC offshore substations can be distinguished.

The reasons for choosing HVDC instead of HVAC to transmit power from offshore to onshore systems are often numerous and complex [63]. But in most cases the transmission distance to the shore is the key factor.

Basic electrical equipment of HVAC substations includes [62, 64, 65]:

- transformers,
- auxiliary transformers,

- earthing transformers,
- GIS high and medium voltage switchgear,
- backup generators,
- earthing resistors,
- reactors,
- AC filters.

The main purpose of HVDC substations is to convert AC current into DC current. Hence, additional elements at HVDC substations as compared to HVAC substations include [62, 64]:

- IGBT converters with a cooling system,
- smoothing coils,
- DC filters.

Example distribution of HVAC equipment at the OS, taking account of the main parts of electrical equipment, is presented in Fig. 8.

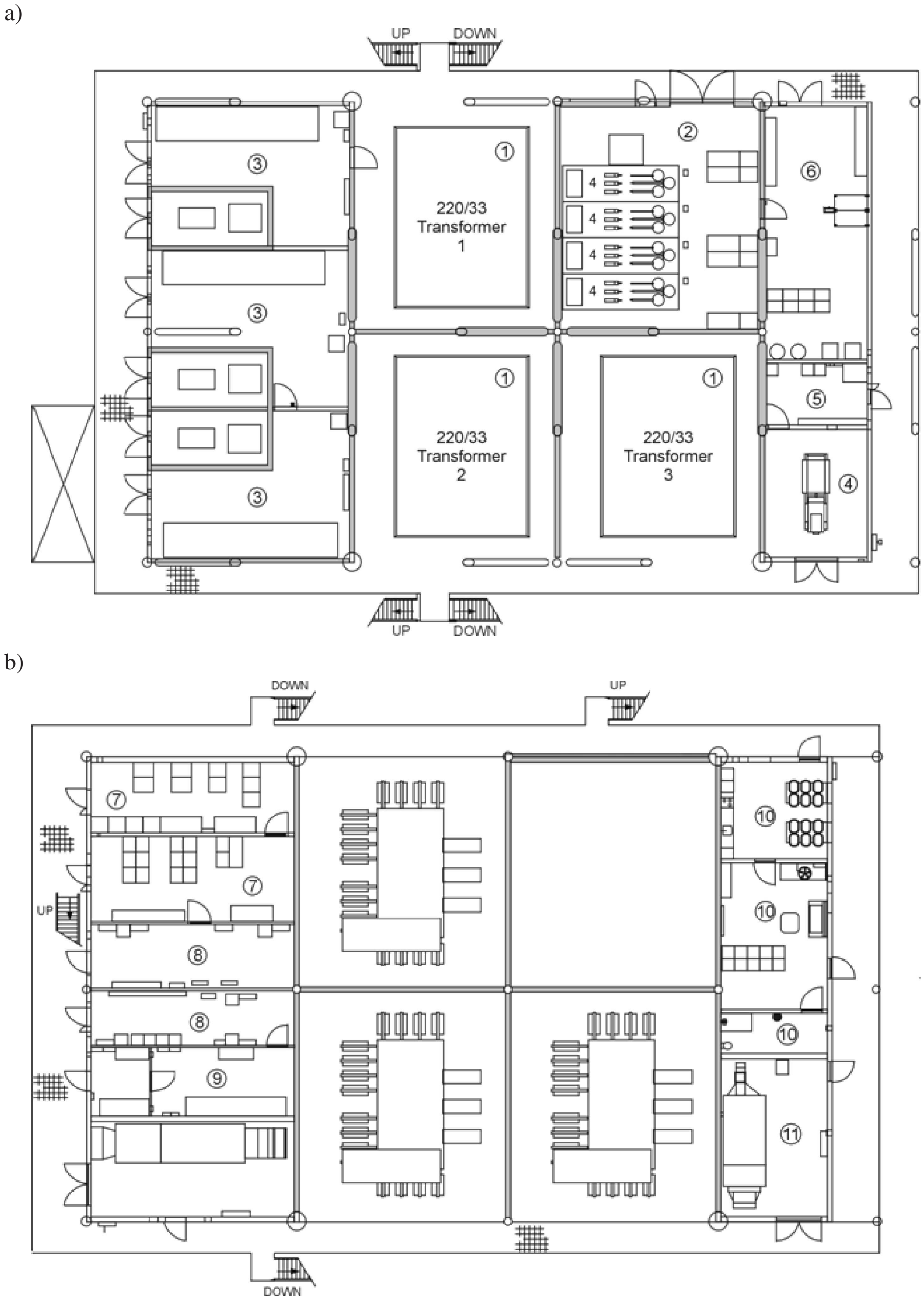

Fig. 8. Kriegers Flak offshore substation: a) lower deck; b) upper deck; (1 – transformer 220/33 kV, 2 – 220 kV GIS switchgear, 3 – 33 kV switchgear, 4 – Diesel generator, 5 – emergency switchgear, 6 – workshop and storage, 7 – SCADA, 8 – 0.4 kV switchgear, 9 – accumulator battery, 10 – social rooms, 11 – heat and ventilation) [66]

6. Offshore substation functions and classification

6.1. Functions of offshore substations in power systems. An offshore substation is an integral part of a power system. Onshore as well as offshore substations should meet the standards defined by the Transmission System Operator. An example of security and quality-of-supply standards related to offshore transmission systems, including offshore substations, is presented in [67].

Due to their current and future functions as well as significance for power systems, the following types of offshore substations can be specified:

- Customer substations – used for exporting power from a single wind farm. Customer substations are collector substations which receive MV transmission cables comprising the wind farm's inter-array cable network. In a customer substation, MV is transformed into high voltage (HV) or extra high voltage (EHV). Unlike typical onshore generation substations, which are connected to several other substations, the power export transmission system of offshore customer substations is developed as a radial line connected by means of an external cable.
- Hub substations – used for power export from several wind farms. Two or more HV (or EHV) cable lines exporting power from individual wind farms are connected to the hub substation radially. A hub substation may house transformers that transform HV into EHV. Consequently, hub substations can be designed as single- or multi-voltage substations.
- System substations – they have connections (through submarine cable links) to at least two different offshore hub substations or at least one connection to an offshore hub substation and at least one connection to an onshore substation.
- Hub-system substations – having the features of both hub and system substations.
- Interconnection substations – system substations with direct links to power grids of other countries or transmission network operators.
- Load substations – form part of power supply systems for large customers located offshore, such as production platforms.

Some examples illustrating how selected substation types are connected to the power system are presented in Fig. 9.

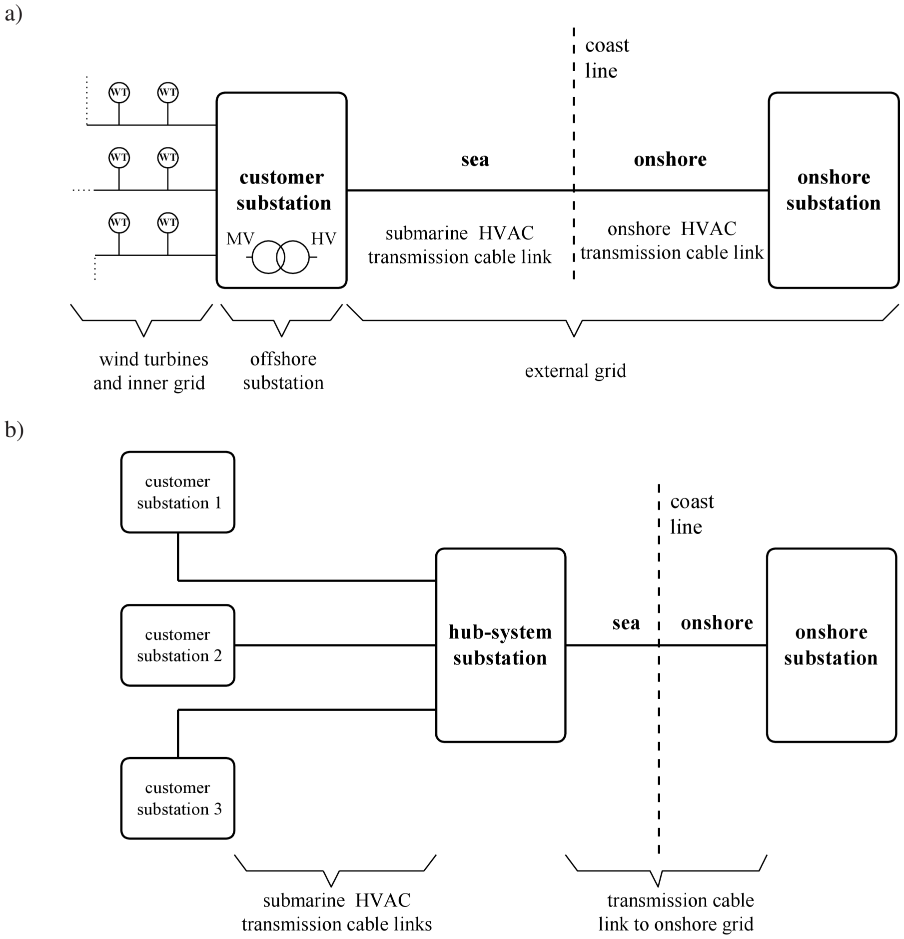

Fig. 9. Typical connection arrangement: a) customer substation (link to onshore substation), b) hub-system substation

6.2. General classification of offshore substations. The main reason for the construction of offshore substations is the need to export energy from the offshore area and transmit it to onshore consumers. Offshore substations may also be an important element of an offshore grid used for the distribution and transmission of power within the framework of international cooperation.

In general, an offshore substation is a network connection point located off shore that collects and distributes electrical power and transforms it into various voltages. Offshore substations, like onshore substations [68–70], can be classified by different criteria. Table 5 shows a comprehensive classification of offshore substations. Table 5 presents a large variety of offshore substation solutions. For example, depending on the size of the project, there may be more than one offshore platform used for the substation's needs. Moreover, a substation can be constructed as a manned installation. In such case, personnel is normally present on the platform at all times. Other substations are normally unmanned, and personnel is only expected to come for inspection and maintenance.

Table 5
Offshore substation classification

Criterion	Type of substations or switchyards
functions of substation in a power system	• customer (or collection) substations • hub substations • system substations • hub-system substations • interconnection substations • load substations
size of switchyard	• large switchyard (more than 10 bays) • standard switchyard (10 or less bays)
transmission technology used for energy export	• HVAC substations • HVDC (or converter) substations
number of power transformers installed in	• single-transformer substations • multi-transformer substations
automatization	• classical substations • smart substations
personnel	• unmanned substations • manned substations
number of platforms	• single-platform substations • multi-platform substations

7. Offshore substation design

In the offshore substation design process, the following considerations should be addressed:

- Location of offshore substation.
  Since the location of the offshore substation has a significant impact on both the layout and total cost of cables, the optimized location of the OS is expected to be found concurrently with the optimized cable connection layout [54, 55]. In a simplified case, an offshore substation is installed ideally within the central area of the wind farm to minimize inner grid conductor lengths and optimize loss efficiencies within the inner grid [71, 72]. It should be stressed that a safety zone that is free of obstacles must be kept around the offshore substation's platform.
- Number of offshore substations.
  For large wind farms, multiple substations are required, each with their own export cable to the shore, providing for some redundancy to the export system [73]. Most projects to date have only required a single substation, but it is anticipated that future projects will use multiple substations if the expected energy output is more than approximately 500 MW.
- Structural design.
  The main problems of structural design include [64, 74]:
  - environmental conditions (i.e. wind, sea currents, waves and levels, etc.) and stresses,
  - topside weight and center-of-gravity envelope,
  - corrosion protection,
  - geotechnical investigations,
  - marine operations [73].

  In general, the technical lifetime of the structure is typically scheduled for 20–25 years. Certain standards and recommended practices should be considered in structural design. Some examples of such standards are presented below [64, 75–77].
- Electrical substation layout.
  Substation electrical layout considerations typically address [78, 79]:
  - volume of the topside (dimensions),
  - substation busbar configuration,
  - necessary degree of reliability and redundancy,
  - number of incoming lines, step-up transformers and reactive compensation devices,
  - special power system demands such as minimum short circuit power.

  The number of busbars and the number of breakers per substation feeder determine redundancy, the associated expected failure/outage rates, complexity and cost [60, 80]. Some of the most common substation busbars configurations are listed in Table 6.
- Occupational health and safety.
  Offshore substations are equipped with telecommunication systems to enable onshore-based remote control of the substation. However, skilled personnel must be available on the site, in particular in case of an emergency or for maintenance. The engineering complexity of offshore substations, where various technological processes are carried out, and environmental conditions on the platform site can have a number of adverse health effects on their personnel [81].

Table 6
Substation busbar configuration comparison [82, 83]

Substation configuration	Relative cost comparison
single busbar, single breaker	100% 120% (with section breaker)
double busbar with breaker and a half	145%
double busbar, double breaker	190%
ring busbar	125%

8. Conclusions

Like other European countries, Poland has taken steps to develop offshore wind energy. The results of wind power testing for Polish offshore areas have shown that the combined capacity of potential OWFs is about 7.5 GW. Current project work is focused on several OWF projects. The most advanced work involves two OWFs with combined capacity of 2.245 GW.

In order to transmit electrical energy produced in offshore wind farms to onshore consumers, it is necessary to build the appropriate infrastructure. Offshore power engineering solutions differ from onshore ones, including with regard to electrical substations. Offshore substations are indoor structures due to environmental conditions and limited space. They need a special structure consisting of the substructure and the topside. Wind farm capacity, power transmission, electrical substation layout as well as marine conditions all influence the substation design.

OWF platform structures are mainly bottom founded (gravity-based or on piles). In general, platforms accommodating a substation consist of electric power equipment and a selection of necessary equipment and engineering systems distributed on several decks. The engineering complexity of offshore substations and environmental conditions on the site where the platform is situated can have a number of adverse health effects on personnel.

Due to difficult conditions prevalent in the marine environment (including humidity, salinity and wind), OS electrical equipment should meet very high robustness standards. At the same time, it should be very compact due to limited platform space. In addition, electrical and engineering systems on the OS should be designed in such a way as to ensure reliability and – as far as possible – maintenance-free operation.

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