ASSESSMENT OF COLLECTOR NETWORKS FOR OFFSHORE WIND POWER PLANTS

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REZUMAT. In cadrul acestei lucrări sunt analizate soluţiile tehnice posibile pentru reţelele interne de MT ale parcurilor eoliene offshore. Condiţiile din largul mărilor prezintă unele provocări în ceea ce priveşte funcţionarea şi mentenanţa. Este prezentată o analiză comparativă pentru diferite configuraţii ale reţelei interne ale unui parc eolian offshore de 90 MW luând în considerare costurile pe care le implică şi fiabilitatea acestora. Pentru fiecare tip de configuraţie s-au calculat secţiunile necesare ale cablurilor şi s-au analizat pierderile de putere pentru fiecare configuraţie utilizând programul ETAP.

Cuvinte cheie: parcuri eoliene offshore, topologii de reţele electrice, pierderi de putere, fiabilitate.

ABSTRACT. In this paper, the possible technical solutions for MV collection network of offshore wind power plants are analyzed. Marine environment present challenges for operation and maintenance. A comparative analysis of collection network layouts for a case study 90 MW offshore wind power plant is presented, and the costs they imply and their reliability are discussed. For the various analyzed layouts, the necessary cable sections were calculated, and were implemented in ETAP in order to calculate the power losses.

Keywords: offshore wind power plants, collector network layouts, power losses, reliability.

1. INTRODUCTION

In Romania, in the year 2012, the total installed power in onshore Wind Power Plant (WPP) has reached 1900 MW and the construction of an Offshore Wind Power Plant (OWPP) in the Black Sea is still a debate subject. But globally, in the last years, with the technology development, offshore wind power has spread to all countries and became the main source of global focus for renewable energy development. Since 1991, when the first OWPP was built, OWPP in more than 50 European locations were installed.

During the first six months of 2013, seven OWPPs were installed and grid-connected in Europe, for a total of 227 offshore wind turbines. This brings the total installed and grid-connected capacity to 1939 offshore wind turbines, representing 6040 MW installed in 58 OWPP in ten European countries [1]. The capacity of these WPPs spans from several hundreds of MW to 5-10 GW.

At the end of 2012, the UK had the largest amount of installed offshore wind capacity in Europe (2947.9 MW): 58.9% of all installations, Denmark followed with 921 MW (18.4%). With 380 MW (7.6% of total European installations), Belgium was third, followed by Germany with 280 MW: (5.6%), the Netherlands with 246.8 MW (4.9%), Sweden with 163.7 MW (3.3%), Finland with 26.3 MW (0.6%), Ireland (25.2 MW), Norway (2.3 MW) and Portugal (2 MW) [2].

At the end of 2012, about 50% of the world's OWPP had been equipped with a CG wind turbine generator (WTG) transformers (SLIM® and BioSLIM®). When compared to conventional transformers, they are smaller, have higher power ratings per volume, have an up to 50% lower no-load loss and are able to withstand more austere climatic environments.

Offshore locations present challenges for operation (O) and maintenance (M). A fault in the case of OWPP leads to a longer period of non-delivered energy. Effective short-circuit detection for safe operation and cost saving during O&M period are possible thanks to smart designs.

In the present paper, the possible connection types of a medium voltage internal network of an OWPP will be investigated: radial, star, single sided, and double sided collection networks. Decreasing the overall cost is a strategic driver in substation design. From the technical point of view with a 90 MW OWPP case study, for all type of connections, the cable sections were determined and the power losses were calculated in ETAP program. For a full analysis, the reliability for each type of connection and the associated costs are discussed.

2. TECHNICAL SOLUTIONS FOR COLLECTION NETWORK

In [3], [4] are analyzed schemes for onshore network connection in terms of technical, economic and safety aspects. Beside all this, the offshore collection system aggregates the wind turbines (WT) and connects them to a central collection point (offshore substation). The OWPP collector system generally consists of WTGs, step-up transformers, switching equipment, protection relays, cables which collect the power from each WTG, and collector substation where the collected power is transported to the 50 Hz system and is schematically illustrated in Figure 1 [5].

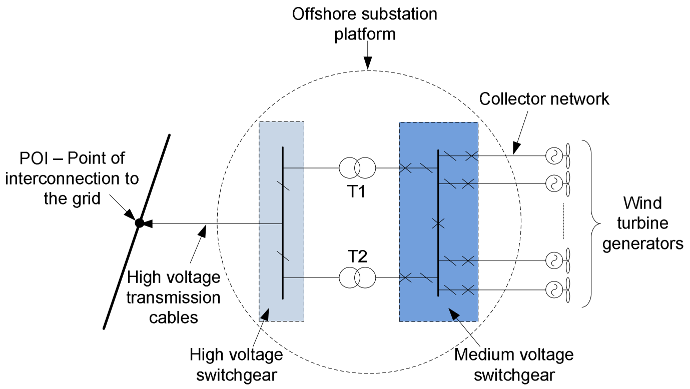

Fig. 1. The OWPP elements.

There are several solutions for configuring the OWPP internal grid. For choosing the best connection solution, the reliability, power losses and investment costs must be taken into account.

Radial collector network

The radial topology is illustrated in Figure 2. This represents the simplest collection system and its main advantage is the relatively low cable costs [6]. The maximum number of wind generators within a group is determined by the installed power capacity and the electrical current rating of the cable. This connection is used for the internal network of the first OWPP, Horns Rev of 160 MW in Denmark.

The main disadvantage of the radial collector network as connection type is the low reliability in case of failure of cables or switches, which will affect all connected generators [7].

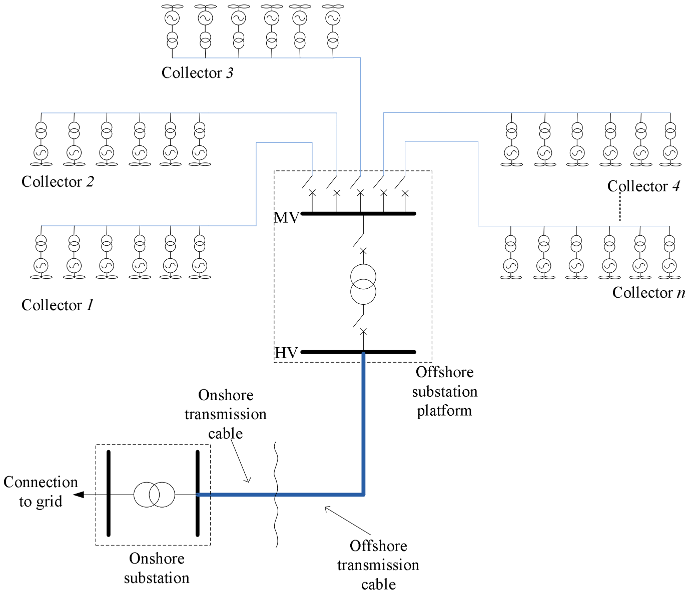

Fig. 2. Radial collector network.

Star collector network

This connection topology is realized connecting each wind generator from a collector system to a central generator connected to the offshore substation.

The failure of a cable connecting a generator will not affect other generators connected to the same point and thus has a high level of reliability.

The main disadvantage of the star topology is the high investment costs of cables compared with the radial design [8]. In Figure 3 is illustrated the general scheme of a star collector network.

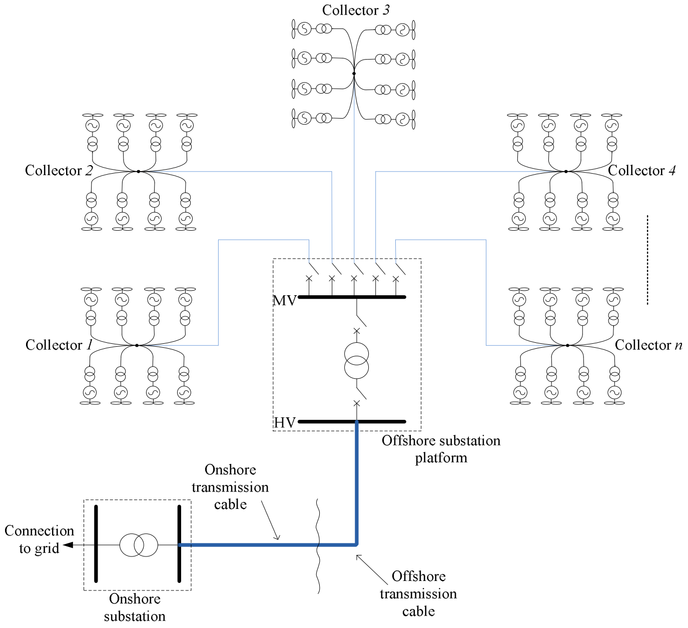

Fig. 3. Star collector network.

Single sided ring collector network

A single sided ring scheme is normally operated in open ring, but is sized to operate in closed ring. A single sided ring scheme is illustrated in Figure 4. In the open ring functioning, in case of a fault, it is necessary to remove the faulty part and restore supply using the redundancy cable.

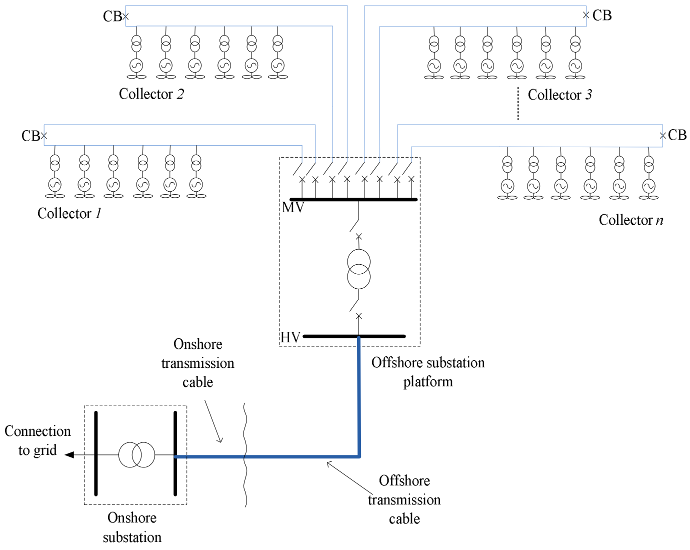

Fig. 4. Single sided collector network.

Compared to the radial design, the main disadvantages of this configuration are high investment costs associated with the redundancy cable and higher rated cables between wind generators. Even with the increase in cable costs compared with the radial collector network, this type of layout is recommended for OWPP with high power installed [9].

Double sided collector network

Double sided collector network, illustrated in Figure 5, represents two collector groups connected in parallel in order to provide redundancy and involves cables of larger sections compared with the previous cases [6].

In order to determine the required cable sections the worst case scenario is considered, in which a failure occurs in one of the cables connecting the power station and all power in that group must be evacuated by cables connecting the other group (operating with closed circuit breaker) [10]. This system has higher reliability compared to the radial system. In case of fault, the radial connection (in normal operation) can be reconfigured and the energy produced is not lost. Because of higher cable sections, higher cable length (connections between collector groups), more complex system (depending on location and number of reconfiguration switches), this solution implies higher investing costs [11].

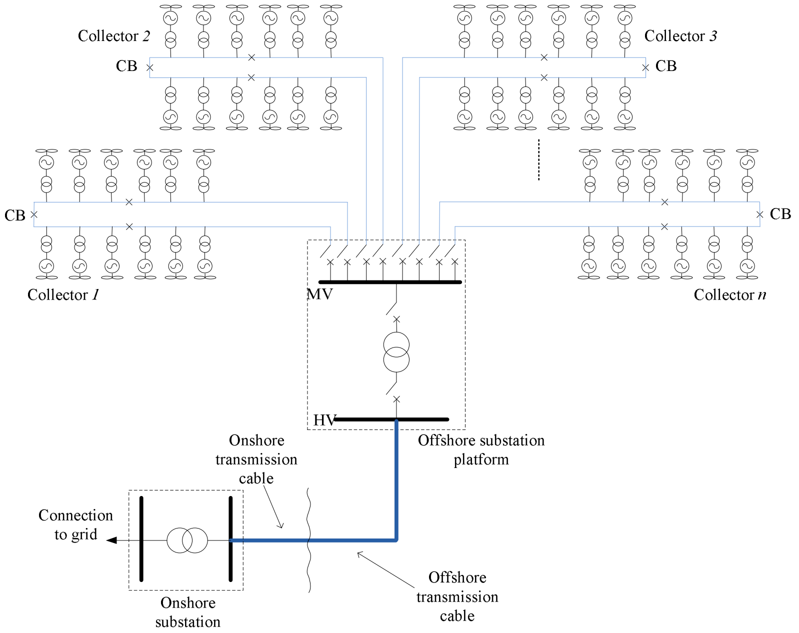

Fig. 5. Double sided collector network.

3. CASE STUDY: OWPP - 20 X 4.5 MW

In this section, the MV collector network of an OWPP of 90 MW composed of 20 wind generators of 4.5 MW is analyzed.

Each WTG is equipped with power transformers 0.69/34.5 kV. The 34.5 kV collector network is interconnected through a power transformer to the 110 kV transmission line. The 4 collector networks presented in section 2 (radial, star, single sided ring, and double sided ring) and illustrated in Figure 6 will be analyzed.

From the technical point of view, for these types of connection the sections and the power losses were calculated for the considered 90 MW OWPP.

To calculate the power losses the ETAP program was used, which provides a quick and easy modeling. The losses in the MV internal network of an OWPP can be divided into turbine losses and collection system losses (ohmic losses). The collection system losses (in cables) are obtained using relations (1) and (2), [12]:

$$\Delta P_{cable} = 3 \cdot R_{cable} \cdot I^{2} \tag{1}$$

$$R_{cable} = R_{0}\left(\Omega / m\right) \cdot l_{cable} \tag{2}$$

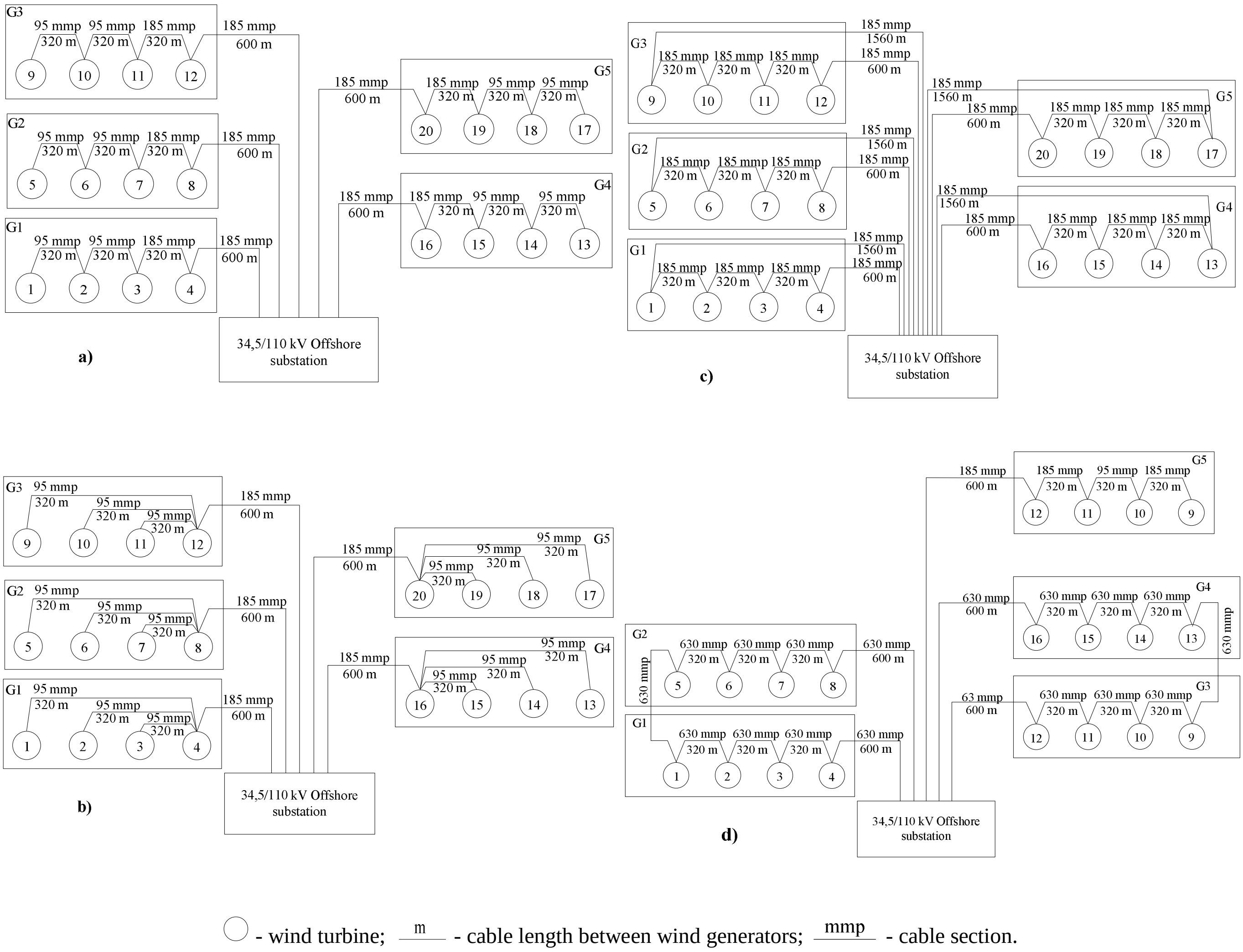

Fig. 6. Layout of collector networks: a) radial; b) star; c) single sided ring; d) double sided ring.

The transformer losses are obtained using relations (3), (4) and (5):

$$\Delta S = \sqrt{\Delta P + \Delta Q} \tag{3}$$

$$\Delta P = \Delta P_0 + \Delta P_{windings} = n \cdot \Delta P_{0,rated} + \frac{\alpha^2}{n} \cdot \Delta P_{scc,rated} \tag{4}$$

$$\Delta Q = \Delta Q_0 + \Delta Q_{windings} = n \cdot \frac{i_0}{100} \cdot S_n + \frac{\alpha^2}{n} \cdot \frac{U_{scc}}{100} \cdot S_n \tag{5}$$

where: $\Delta P_0, \Delta Q_0$ – open circuit real and imaginary power losses; $\Delta P_{windings}$, $\Delta Q_{windings}$ – windings losses; n – number of transformers; i_0 – open circuit electrical current; u_{scc} – short circuit voltage rate; $\Delta P_{scc,\ rated}$ – rated short circuit power losses, S_{rated} – rated power, and $\alpha = \frac{S}{S_n} = \frac{\sqrt{P^2 + Q^2}}{S_n}$.

The power losses results of collector networks implemented in ETAP are reported in Figure 7.

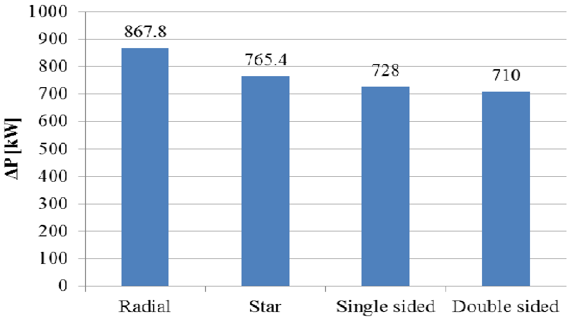

Fig. 7. Power losses in function of layout of collector networks.

5. CONCLUSIONS

✓ More and larger wind farms are being located offshore. Further evolution of very compact design both of separate equipments as well as space-efficient overall layouts. From the comparative analysis of the layout options of electrical collector network, the results lead to the conclusion that the power losses varies with the internal network configuration. The ringed layouts offer the lowest amount of power losses in normal operation, but the costs are higher than the radial or star design. For OWPPs, in this paper is considered that no redundancy is required. For these, the repair time in case of fault is not very high with respect to the costs of not-supplied energy. In case of OWPPs, for small or medium capacity plants the redundancy is not feasible.

✓ For large OWPPs, in case of fault occurrence the repair time is higher in the marine environment, and is necessary to consider a redundancy for evacuating the power produced by wind generators in spite of higher costs. New innovative HV-AC grid connection design increases reliability and availability and reduces cost by decreasing the weight of the platform, towers and foundations. The offshore substation design can be performed according to any acknowledged standard (DNV, IEC, NFPA, ISO etc.) but one European Grid Code will definitely improve this standardization.

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