ABSTRACT

Nowadays the demand for energy is increasing in the world, but at the same time conventional energy resources are becoming expensive and more pollutant. All these facts are leading the countries to focus on renewable energy sources. In this field Offshore Wind Power Plants (OWPPs) are becoming increasingly relevant mainly in Europe. Currently, and because of the environmental and social legislation, OWPPs are forced to be constructed further from shore. There are three main factors to be covered when designing AC electric system of OWPPs: investment cost, system efficiency, and system reliability. The present project is focus on the first two key factors, and also considers a stochastic optimization of the electric system of an OWPP operation in order to minimize the investment and operational cost. GAMS and MATLAB softwares have been used to implement the model, obtaining a basic engineering tool to design and take decisions for the electric power system applied to OWPPs.

1 Motivation

Wind energy is one of the most profitable renewable energy, proven technology to meet current and future electricity demands. The cost per MW of installed capacity of an OWF is much higher in comparison with an onshore wind farm.

The offshore conditions are favourable in comparison with the sites on land: stronger and steadier wind speeds, no obstacles, etc. However, advantages contrast with the increments of installation and maintenance costs, which must be compensated.

Due to the increase of power capacity of the current and future OWFs, the adequacy of the electric power system design becomes critical, because of its extend influence in efficiency, cost, reliability, and performance. For these reasons, the electrical power system needs to be optimized in order to minimize costs, maintaining also a good level of efficiency.

2 Purpose and scope

The main goal of the present project is to develop a design tool that optimize the electric power system of the OWPP, but also takes wake effect into consideration, minimizing costs related to component investment and ohmic losses within the system.

The scope of the model is focused on OWPPs with a MVAC collection grid and an HVAC or MVAC transmission system. Stochasticity is considered by taking into account the intermittent behaviour of the wind.

3 Resources

The main program has been developed in GAMS software, whilst MATLAB language has been used to calculate the wake effects within the OWPP. Thus, the results obtained from MATLAB have been introduced as input data in the GAMS code. The optimization problem is a mixed integer quadratic constraint programing (MIQCP) and the solver used is ***Cplex.***

4 Problem statement

First of all, it is necessary to obtain the specific data relating to the studied OWPP such as type of turbine, layout, and so on. Wind speed distribution data and the location of the OWF are assumed to be known, as well as, the turbines positions in the polygon site and the PCC.

In this thesis will be studied two main and general layouts for the electric power system. The first layout (Fig. 4-1) considers all wind turbines are connected by MV cables, gathering in a CPP with an offshore substation. Then power is transmitted to the PCC through a HV line.

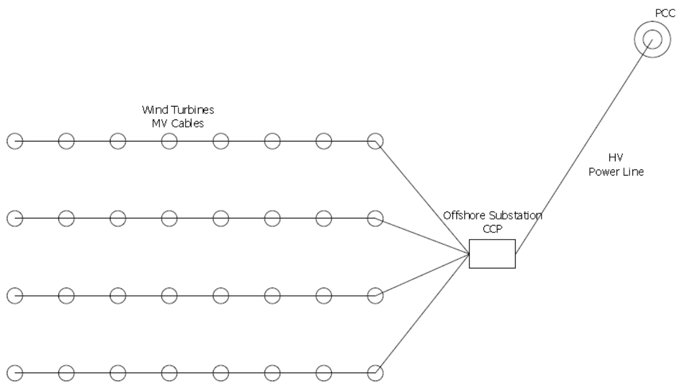

Figure 4-1: First electric power system layout.

The second layout (Fig. 4-2) considers the connection of all wind turbines by MV cables, gathering physically, but not electrically, in a CCP and transmiting the power directly to the PCC. Existence and location of CCP are decisions of the problem (as previous case)

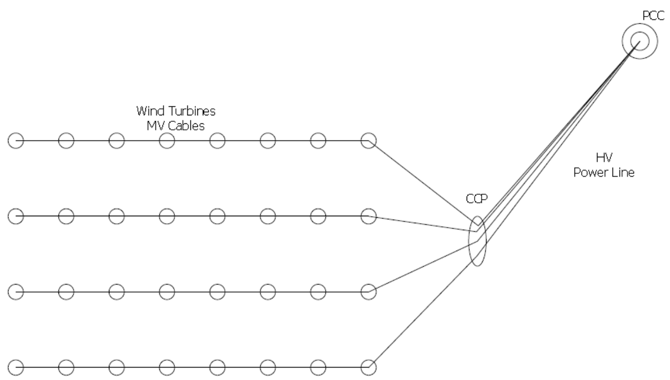

Figure 4-2: Second electric power system layout.

It is assumed that the wind speed, v, is distributed according a Rayleigh probability density function of parameter c i.e. a Weibull probability density function of parameter k equal to two. Additionally, in this project is assumed only one wind direction.

The first program executed in MATLAB is used for calculating important inputs. The most important output is the power output of each wind turbine for every scenario. Finally, it is implemented the GAMS programming to carry out the main optimization. Using the two different mains programs, it is carrying out the optimization of the electric power system.

The list of sets studied in the implementation of the model are the following:

- i, j generic turbines.
- sub offshore substation (CCP).
- p collection point of MV cables (CCP).
- m, h type of MV or HV cables.
- t type of power transformer of the offshore substation.
- e wind speed scenario.

5 Case Study

A particular real case was used to validate the model. The wind farm used was the Barrow Offshore Farm (BOWF). It is located in the west of England at the East Irish Sea.

This park consists of a total of 30 wind turbines distributed as shown in the figure 5-1, and the distance are 500 m in the normal direction to wind and between rows is 750 m .

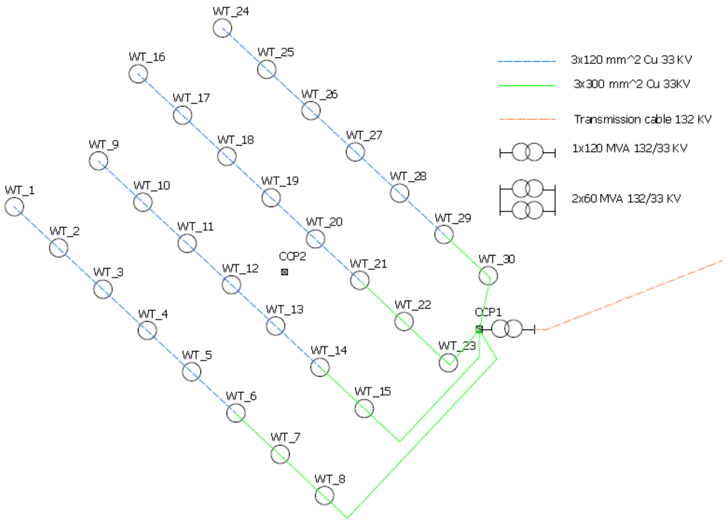

Figure 5-1: Actual layout of the electric power system of BOWF.

The total installed power is 90 MW). It has to be taken into account some simplifications due to the complexity of the programming: two possible locations of CCP were considered, the cable connections between turbines were limited to those pairs which are at a straight-line distance of less than 700, two types of MV and HV cables were chosen, also two power transformers, twenty-six wind scenarios.

6 Test and results

Using MATLAB, some important and relevant data are obtained. The main one is the speed matrix, which contains the speed facing each turbine for every scenario. Therefore, using this information is obtained the wind power generation matrix. Other important data extracted is the period duration of scenario e , T^e (Table 6-1).

		Speed interval Low (m/s)	Speed interval High (m/s)	Probability of scenario e (%)	Period duration of scenario T^e (h)
WIND SPEED SCENARIOS	e1	0	1	0.850%	1489.4689
	e2	1	2	2.507%	4392.9130
	e3	2	3	4.039%	7076.2176
	e4	3	4	5.373%	9413.0197
	e5	4	5	6.453%	11305.0659
	e6	5	6	7.243%	12688.8673
	e7	6	7	7.727%	13538.5770
	e8	7	8	7.914%	13865.0148
	e9	8	9	7.826%	13711.2588
	e10	9	10	7.503%	13145.6254
	e11	10	11	6.994%	12253.1037
	e12	11	12	6.351%	11126.3759
	e13	12	13	5.626%	9857.4570
	e14	13	14	4.869%	8530.7567
	e15	14	15	4.120%	7218.0621
	e16	15	16	3.411%	5975.6211
	e17	16	17	2.764%	4843.2173
	e18	17	18	2.195%	3844.9140
	e19	18	19	1.707%	2991.0165
	e20	19	20	1.302%	2280.7626
	e21	20	21	0.973%	1705.2877
	e22	21	22	0.714%	1250.4908
	e23	22	23	0.513%	899.5446
	e24	23	24	0.362%	634.9012
	e25	24	25	0.251%	439.7464
	e26	25	26	0.171%	298.9333

Table 6-1: Period duration of each wind speed scenario e, in hours.

Furthermore, it is showed the main results of the optimization made in the GAMS software. The current electric power system layout of BOWF is shown in Fig. 5-1.

The cost of the electric power system layout of BOWF, calculated from the model, is shown in Table 6-2.

	Actual layout	optimal solution of reference literature	optimal solution
Investment Cost in components C_{inv} (million €)	25.15	25.23	21.55
Cost associated with energy not served C_{unav} (million €)	5.87	5.29	--
Cost asscociated with Power Losses C_{loss} (million €)	3.94	4.09	4.01
TOTAL COST (million €)	**34.96**	**34.62**	**25.56**

Table 6-2: Comparison of costs.

In this table is also shown the solution of the optimization of the referenced literature where is taken into account the stochasticity of the reliability. The optimal solution from the model is shown in Fig. 6-1 and Table 6-2.

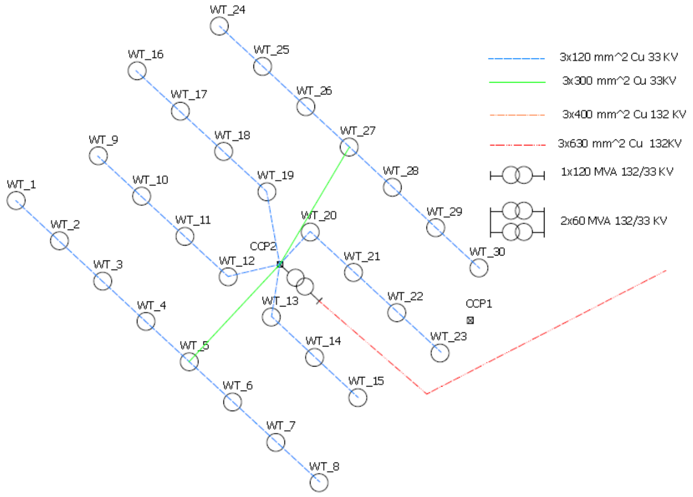

Figure 6-1: Optimal solution for the electric power system of BOWF.

According to the results extracted from the GAMS software, it is obtained that redundancies in MV cables, HV cables or power transformers are not required. Moreover, as in the present project the reliability is not taken into account, the cost associated with energy not served (C_{unav}) is zero.

As you can see in the Fig. 6-1 the optimal solution of the present project is quite different in comparison to the actual layout. The offshore substation is located in *CCP2* and the inter-array connections, between turbines of the same raw, is made by means of MV cables of 120 mm^2 cross-section. Then the groups of three, four, seven and up to eight turbines are joint to the substation using MV cables of 300 mm^2 cross-section. The selected power transformer is one 120 MVA and from here to shore the electricity goes through a 630 mm^2 HV cable.

7 Conclusions

This model covers the main aspects that determine the layout of the electric power system of OWFs: investment costs and system efficiency. An interesting and dynamic decision support model for optimizing ac electric power systems of OWPPs has been presented in the present project. Also, an important aspect to model OWFs as the stochasticity in wind speed has been taken into account

The location of the OWF is also considered in this model. Likewise, the model can handle a range of CCP locations. A large variety of OWPPs may be studied with this model because it can deal with electric power systems with or without offshore substation.

As you can see in the Fig. 6-1 the optimal solution of the present project is different in comparison to the actual layout. This permit to get savings mainly in component investment costs. Moreover, checking the results on Table 6-2 is seen the model works properly as they are close to the reality, at least when measuring the same studied parameters.

The reason why a 630 mm^2 cross-section HV cable has been selected for the model instead of a 400 mm^2 cross-section cable, is due to: equations 23, accounting for energy losses, and 24 whose objective is to minimize the total costs, give this output as solution because it is searched not only a cheaper cable, but also one which has less energy losses (also less cost associated to this factor). According to literature by means of using larger conductor, the load losses primarily due to the ohmic losses can be reduced.

Moreover, the chosen optimum cable routing is quite suitable since it is very important try to avoid cable crossing when it is possible. Cable crossing is highly not recommended in practice, because building one cable on top of another is expensive and increases the risk of damages.

Considering ring layouts for the MV collection system or locating more than one offshore substation are some of the possible extensions to be performed in the model. Other important improvement could be the addition of several (instead of only the main one) wind directions in order to take a more realistic simulation, taking into account the wind rose and the Weibull parameters (probability) of the location of the OWPP.

System reliability assessment is maybe the most interesting improvement to be taken into account for future versions of this optimization model. This assesses the possibility of having redundancy for system components subject to failure.