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Chapter 8

Conclusions and Future Work

From the analysis carried out in this report is clear that it is possible the energy transmission from the offshore wind farms via AC transmission within some rated power and rated voltage boundaries.

To focus the analysis in a specific case, there is analyzed the transmission of the 150 MW at 150kV to 50Km to the shore. In this way, upon this configuration several key issues of the AC transmission systems are analyzed.

Firstly, there are analyzed submarine cables, the way to represent electrically submarine cables and several options to model the cable.

Once the submarine cable has been modeled and validated. The first key issue to analyze is the management of the reactive power flowing through the submarine cable. This analysis shows that a proper reactive power management can reduces significantly the active power losses and the voltage drop in the submarine cable. Furthermore, different ways to achieve this reactive power management are compared, such as the use of fixed inductances at both ends of the line.

So, comparing the reactive power management based on fixed inductances at both ends of the line, with the variable compensation at both ends. It is possible to see that the both methods have similar improvements. For both ways, the maximum voltage drop, the maximum active power losses and the required maximum current for the cable are exactly the same. As a result is achieved as a conclusion that the fixed inductances at both ends are the best option to manage the reactive power through the submarine cable.

Another key issue of the AC transmission configurations is the undesired harmonic amplifications due to the resonances of the system. Thus, using the developed offshore wind farm model as the base scenario, the analysis of its frequency response is carried out. Estimating the resonances of the system and measuring the influence of the main components of the transmission system in its frequency response.

From the results of this study, it is possible to observe that the offshore wind farms have the potential to amplify low order harmonics due to the iteration between the capacitive component of the submarine cable and the leakage inductance of the step-up transformer.

At this point, highlight that the present analysis as a first approximation does not takes into account the effect of the control strategies of the wind turbines. There are not considered control strategies oriented to mitigate filters avoiding the resonance, and neither is considered further and more complex analysis about the harmonic risk or problems related to the iteration between the control strategies of the wind turbines

As any other installation, offshore wind farms must be protected against different eventualities. Moreover, the behavior of these types of generation plants during any eventuality, which causes a voltage drop at the point of common coupling (PCC), is crucial to ensure the quality and the continuity of the electric supply. Therefore, if this kind of generation systems wants to connect to the distribution grid, they have to satisfy the grid code requirements of the system operator (SO).

In conclusion, it is not enough the normal operation analysis to carry out the pre-design of an offshore wind farms electric system. Therefore, to complete the analysis of the AC transmission configurations, an analysis about the disturbances in the electric connection infrastructure and their effects is carried out.

The analysis performed reveals that the switching actions in the electric connection infrastructure have the potential to cause over current and over voltages. The cause of those transient over currents and voltages is the composition of the electric connection infrastructure itself.

In addition to inductive elements, the electric connection infrastructure of the offshore wind farm has huge capacitive elements, such as the transmission submarine cable or the inter-turbine cable.

In the same way, faults or dips at the PCC, which provokes the de-energizing and energizing of the submarine cable also causes dangerous transient over-voltages. Due to this fact, the power electronic devices of the offshore wind farm must be provided with the proper over-voltages protection system.

Another point evaluated in this book is the behavior of the offshore wind farm upon voltage dips at the PCC, from the point of view of the REE grid code requirements.

As one of the most important requirement, the reactive power injection to the main grid during voltage dips in the PCC is analyzed. The submarine cable generates a huge amount of capacitive reactive power in normal operation. Nevertheless, if the voltage applied to the cable drops, the submarine cable can generate inductive reactive power.

As a result, the submarine cable does not help injecting capacitive reactive power during voltage dips at the PCC. Moreover, as the cable can generate inductive reactive power, the offshore wind farm or its auxiliary equipment have to be dimensioned to inject at the PCC the required capacitive reactive power plus compensate the inductive reactive power generated at the cable.

In this way, the huge amount of inductive reactive power generated in the transmission system makes unattractive the use of a STATCOM to inject the main amount of reactive power during voltage dips.

However, full-converter wind turbines can be very helpful to fulfill the grid code requirements at the PCC. But, due to the fact that the wind turbines are located far away from the PCC, their reactive current injection characteristics for voltage dips have to be adjusted.

Therefore, the proposed solution priorities the use of the grid side converters of the wind turbines to reduce active power and inject the biggest part of the required reactive power and the STATCOM only as auxiliary equipment.

Note that the objective of the present book is the development of a methodology or a sequence of analyses, to make the first approach to the design of the offshore wind farms electric connection infrastructure. In other words, the objective is the identification of the problematic aspects of the energy transmission and grid integration by applying the sequence of analyses.

As a result, the present book does not define in detail several advanced design features or technological aspects. Thus, a more deep analysis of the identified problematic aspects is needed to design an advanced or detailed electric connection infrastructure.

In this way, from the analyses carried out, it is seen that the protection system of the converters has to be evaluated more carefully. Due to the fact that the breakers operations or voltage dips at the PCC can cause dangerous voltage peaks for them in the offshore wind farms transmission system.

Finally, this research is based on a specific case which is intended to be representative. So, the proposed solution has been dimensioned to fulfill REE grid code requirements. Consequently, as there are many other system operators and grid codes, the adaptation of the proposed solution to other grid codes will give consistency to this solution. In the same way, further analyses for other specific cases (other rated powers and lengths to shore) will complete this evaluation.

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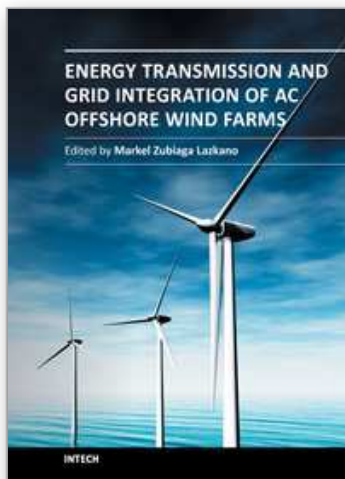
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This book analyses the key issues of the offshore wind farm's energy transmission and grid integration infrastructure. But, for this purpose, there are not evaluated all the electric configurations. In the present book is deeply evaluated a representative 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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