The Development Of Offshore Wind Generation

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Introduction

The development of offshore wind generation is still in its infancy and set to grow over the next decade. There is no standard, proven electrical connection design for offshore wind farms. Little thought has gone into the risks, costs or loss of revenue that could follow a failure of the electrical system. Not dealing with these issues could make or break a project.

Onshore wind farms have adopted a low capital cost approach to medium voltage (MV) systems. Cabling, switchgear and protection systems are designed to minimise the amount of installed equipment. Consequently most (if not all) the wind farm is disconnected following a fault and the possibilities for reconfiguration and automation are limited. This approach for onshore wind farms is justified due to the low risks of failure, ready access for manual re-configuration and relative ease of locating faults and making repairs. The implications both financial and safety of failures in an off shore wind farm are orders of magnitude greater than those for an onshore wind farm. The offshore environment places restrictions of access to the farm, complicates even the simplest repair and presents its own particular safety risks. Consequently the designs applied to on shore wind farms are not appropriate to off shore wind farms.

Econnect Ltd have been carrying out research to investigate the design of innovative Medium Voltage networks for offshore wind farms, identifying areas for improvement and industry innovation that could be applied.

- A typical 30 turbine off shore wind farm costs about €140 million to build.
- The MV electrical system costs range from around €9.8 to €12.5 million.
- Inadequately designed MV systems can lead to losses in revenue due to electrical failures of as much as €7 million in the lifetime of the project.

The selection of an appropriate MV design is extremely important as it can significantly affect the economics of an offshore project. The research has focused on the following:

- Highlighting possibilities for fault tolerant components and topologies
- Producing wind farm designs using both established and new/innovative equipment configured to maximise generation and minimise failure
- Estimating expected failure rates of wind farm electrical distribution components offshore.
- Developing outline method statements and risk assessments for power failure
- Assessing rough budget costs and timescales involved with system repairs
- Identifying areas of concern and outline methods of improvement through practice or technology

In carrying out this research, Econnect examined 5 MV system designs for a number of current Econnect projects involving real UK offshore wind farms.

Network Topologies

On shore wind farms are generally designed using a radial network topography (see fig1). The same topography could be applied to offshore wind farms. The turbines are connected to strings of cables. In the event of a cable failure all turbines connected to the faulted string are disconnected by the opening of the circuit breaker protecting the entire string. Once personnel have accessed site disconnecting the faulted cable and isolating all the turbines beyond the fault can achieve a part restoration of the faulty string. The turbines beyond the fault will only be restored to supply once the cable has been repaired, in the meantime no power output is possible from these turbines. Therefore a cable fault that is not repaired for a prolonged length of time could have a severe impact on wind farm revenues.

An alternative topography (see fig 2) is to use a looped network. In this arrangement extra sections of cable are used to loop the ends of the strings. If a cable fault occurs on a network of this type, all the turbines can be restored to supply once the faulty cable section has been isolated and the normal open point is closed. The output of all the turbines can now be harvested. It may be the case that in the emergency post fault arrangement the cable rating will limit the output of some of the turbines. However post fault, the looped arrangement will always deliver more energy than a radial network.

A further benefit of looped topologies is that security of supply will be mainlined to all turbines in the event of cable failures. However for Radial topologies an alternative solution is required. As will be discussed later, one of the problems caused by a cable fault on a sub sea cable is that it can leave wind turbines without any power for their auxiliaries for a considerable length of time. This can lead to risk of damage to the turbines.

One solution is to fit diesel back up generators to provide auxiliary power for the turbines. This could either be a small unit per turbine or a large unit placed at the end of a radial array to power all the turbines beyond the fault.

Methods of Switching

As stated above with a looped network all the turbines can be restored to supply and earning money once the faulted cable section has been isolated. Therefore it is important to ask how long it will take to isolate the fault. This partly depends on the method of switching used.

Fig 3 shows the schematic of a typical on shore wind turbine. The switchgear is minimal with only a single circuit breaker to protect the turbine transformer and no additional switches or breakers to protect/isolate faulty MV interconnections. Figure 4 shows a photograph of this arrangement. It shows how the array cables are connected on to switchgear by separable “T” connectors. In order to isolate a faulty cable the entire network needs to be isolated by operating the circuit breaker protectin the entire sting. onshore switchgear then the separable T connectors are unbolted at each end of the cable. To close a normal open point would be the reverse of this.

Figure 5 shows the schematic of a “ring main unit” turbine switchgear arrangement. This arrangement is more appropriate for off shore. Fig 6 shows the physical arrangement of this. The main change to the simple scheme used onshore is that each array cable is terminated onto a switch. Now simply operating the switch at each end of the faulty section can isolate a cable. This operation is faster than unbolting a separable “T” but can be made many times faster by remote or even automatic operation.

In order to take advantage of the remote control feature of the switchgear arrangement shown in figure 5 it is necessary to install the correct protection and control equipment. To detect the position of the fault, cable fault locators could be built into the protection relays at the on shore substation. However a simpler and perhaps a more reliable arrangement would be to install fault passage indicators [1] (FPI) on each cable feeder. An FPI detects the passage of fault current and would send an alarm to the SCADA system. Fig 2 shows the position of the FPIs on a looped network. All the FPIs between the shore and the fault will operate whilst those beyond the fault will not. This would allow the fault to be located. The other requirement is a fault tolerant Scada system so that the alarms can be detected back at the onshore control point and that the remote controlled switchgear can be operated. It must be fault tolerant because the simplest way to communicate with the turbines is via fiber reoptic cables embedded in the sub sea cables. This communication route will almost certainly fail in the event of a cable fault. In networks with looped power cables there will always be two paths for any communications signals, so as long as a method of route switching is used the communications system will be fault tolerant.

On the radial network shown in figure 1, following a shore link cable fault, 33 % of the output of the farm is lost for the time it takes to repair the fault. This is estimated to take 31 days. Because repair times are significant, reconfiguration of the network is desirable to restore part or full output capacity. For a looped network with manual operation it may take up to 36 hours to access site and disconnect the faulty cable in order to reconfigure the network. Therefore after 36 hours, it is possible to export power from all turbines. Full output may not be achieved until the repair is completed after 31 days. With remote operation post fault reconfiguration can be achieved in as little as a few hours thus reducing lost revenues. The reconfiguration of a remote controlled wind farm distribution network depends on the response time of the control room operators. To speed this response time up further automatic re-configuration could be applied.

Combining the network ttopologies with the different Methods of Switching gives 5 different possible wind farm designs:

1. Radial design
2. Radial design with diesel back up
3. Looped design with manual reconfiguration
4. Looped design with remote reconfiguration
5. Looped design with automatic reconfiguration

Met opmaak: opsommingstekens en nummering

Econnect assessed these 5 designs and compared them in an attempt to define the optimum design for typical offshore wind farms.

Failure Rates

Clearly the investment in greater levels of network sophistication needs to be carefully examined. In order to assess the need for MV distribution systems offering “higher availability” it is necessary to evaluate the likelihood of off shore wind farm faults. To evaluate this Econnect investigated the failure rates of the individual wind farm components. The accuracy of failure rates is difficult to asses however Econnect were able to produce a best estimate from the available data [2], [3], [4]. The failure rate data collected was used to derive the expected number and type of failures for a typical offshore wind far as in table 3.

Using the MTTF figures given above the following figures have been calculated for the likely number of MV system component failures for an assumed 20 year lifetime of a typical offshore wind farm. Table 1 is a summary of these.

The looped network has slightly higher failure rates than the radial network. This reflects that the looped arrangement has more switchgear and slightly more cable than the radial network. However the next section will show that the slightly higher failure rate for the looped network is more than compensated for by the increased availability you get from a looped network.

Risks

The following section will deal with three different types of risks associated with the operation and maintenance of offshore wind farms.

- Risks to personnel
- Risks associated with the impact of security of supply to the wind turbines.
- Risk to the project economics

Econnect compared these risks for the different networks designs.

Personnel risks are associated with the transfer of staff from the shore to the wind farm. After a fault, personnel are required to visit the site to re-configure the network and to repair the fault. The different network designs require a different number of visits post fault to re-configure the network. The more visits to site and the more transfers between turbines the higher the personnel risks.

Obviously designs requiring manual reconfiguration expose personnel to the highest risks when considering reconfiguration operations.

There are two main risks associated with the impact of security of supply to the wind turbines. Firstly those that are associated with damage that could occur to an offshore turbine if it was left without auxiliary power for a prolonged period of time. Examples of this include damage due to condensation, gearbox damage if the turbine hasn't rotated and prolonged re-start times if the turbine controller has been without power for a significant period. The other risk is that losing power will cause a failure of navigational and aviation lights.

An assessment of the security of supply for a shore link cable failure is shown graphically in figure 7. It shows the impact on security of supply to the wind turbines is greatest for a radial network and is fairly high for a looped network with manual operation. By fitting diesel backup to a radial network or by having a looped network with either remote or automatic switching the impact can be greatly reduced.

Fitting diesel backup to a radial network is the least cost solution to keep supply to all wind turbines adding an extra 5% to the cost of a simple radial network (a looped remote network would add an extra 20% to the cost). However the diesel option may not be the best solution if economic risks are taken into account.

The risks to project economics are the effect faults have on maintenance costs and lost revenue from the generation. The network design has no effect on the maintenance costs. The fault has to be repaired [5] and its cost is the same irrespective of the network design. The network design however, can have a great effect on the amount of lost revenue post fault.

With a radial network assuming a fault on a shore link cable the lost revenue whilst the fault is being repaired could be up to €630,000. From table 1 it is clear that a shore link cable failure is likely to occur 3 times in the life of the wind farm therefore the expected lost revenue from a shore link cable fault could be €1.9 million.

With a looped design with remote reconfiguration again assuming a fault on a shore link cable, the wind farm can now be reconfigured. All the turbines will be generating again not long after the fault. Some turbines may have to run at reduced maximum output but because wind speeds greater than turbine rated speeds occur for only short periods of time it is likely that most of the energy that would have been captured if there hadn't been a fault would still be captured post re-configuration. Therefore it is worth investing substantial sums in the extra equipment needed for a looped design with remote reconfiguration.

As a comparison, for a typical off shore wind farm of 30 turbines the difference in capital cost for a looped design with remote reconfiguration over a radial design is €2.1 million. The above assessment only looked at faults on shore link cables. Table 2 assesses the likely cost of lost revenue for all types of distribution system fault. It estimates a likely cost of over €2.8 million.

The figures quoted are for a typical wind farm approximately 10 kM from shore. If the wind farm was close to the shore and in more sheltered waters then the risk of failure, especially to the shore link cable, would be less and the repair time would also be less. Therefore for a wind farm close to shore the least life time cost solution would be a radial network. However if the farm were further out than 10 kM then it would be worth investing in a looped design with remote reconfiguration. The extra cost for looped design over the radial design is about the same irrespective of how far it is from shore. With a large wind farm further of shore than 10 kM the lost revenue due to failures during the project life time could be as much as €7 Million.

Conclusion

There is no standard, proven electrical connection design for offshore wind farms. Onshore wind farms have adopted a low capital cost approach to MV systems. The offshore environment places restrictions of access to the farm, complicates even the simplest repair and presents its own particular safety risks. Consequently the designs applied to on shore wind farms are not appropriate to off shore wind farms. The selection of an appropriate MV design is extremely important as it can significantly affect the economics of an offshore project.

This work examined radial and looped network topologies. It was shown that in the event of a shore link cable failure looped network topologies were always able to deliver more energy than comparable radial network solutions. It was also shown that looped network topologies offer benefits over radial topologies concerning security of supply to turbines in the event of cable failures.

An assessment of the benefits of increased levels of switching sophistication (manual, remote control or automatic) was then carried out which showed that the main benefit of increasing the investment in switching equipment is the possibility of reducing the amount of lost revenue from the windfarm after a fault.

An estimate of the number, type and duration of electrical failures that can be expected for an offshore windfarm project during its lifetime was made. It was shown that the number of faults was significant and therefore investment in fault tolerant networks could be justified.

The work then examined the risks associated with offshore windfarms. It has found that greater levels of switching sophistication offer the potential to reduce the risks to personnel significantly. It was also shown that the loss of supply to turbines can increase risks of damage to the windfarm and that looped networks can significantly reduce this risk without the need for the provision of diesel back up generators. The work also examined the risks to windfarm project economics. It can be seen that an investment of €2.1 million in a fault tolerant network has the potential to save as much as €7 million over the lifetime of the project.

This work therefore identifies that investment in fault tolerant MV networks for offshore windfarms can bring a number of significant benefits to the offshore wind industry.

Acknowledgements

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Figures

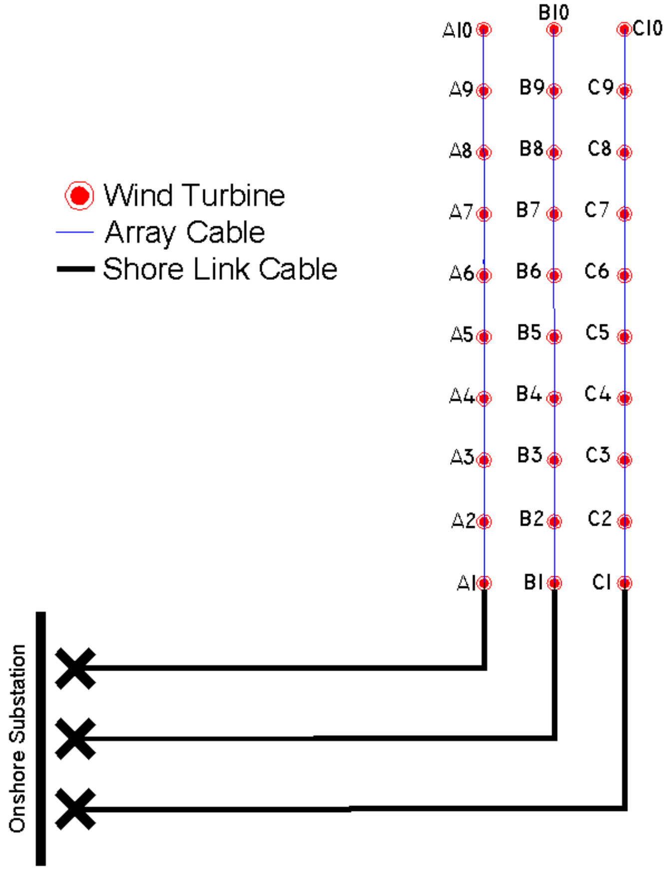

Figure 1: Radial topography

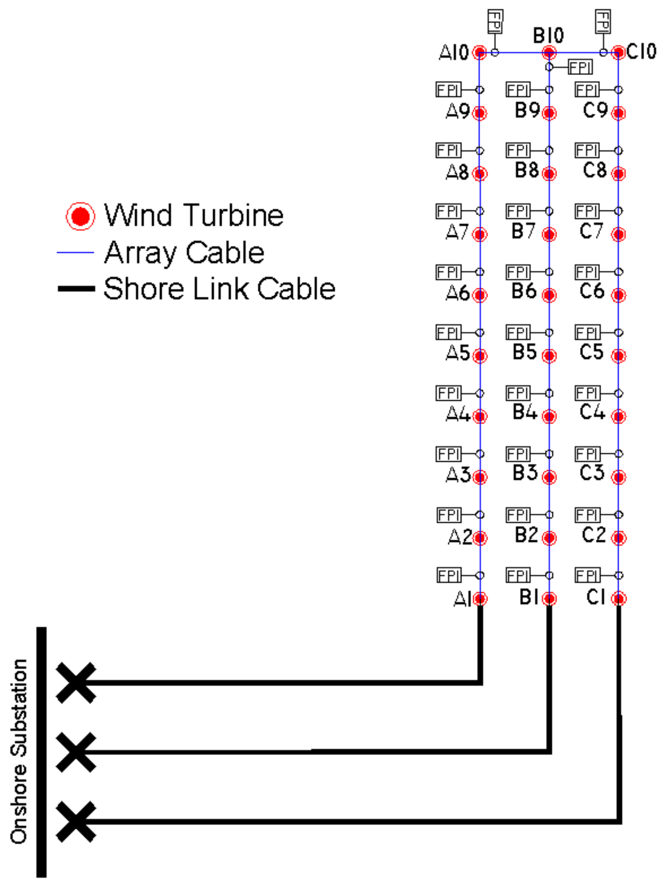

Figure 2: Looped Topography

Figure 3: Simple bolted "T" and circuit breaker

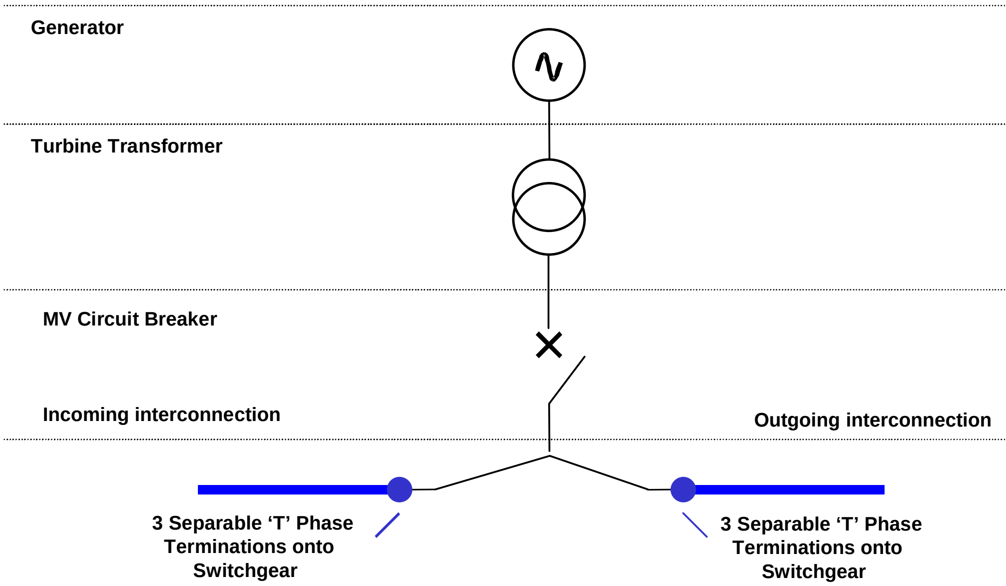

Figure 4: Photo of a bolted "T" arrangement

Figure 5. Ring Main unit arrangement

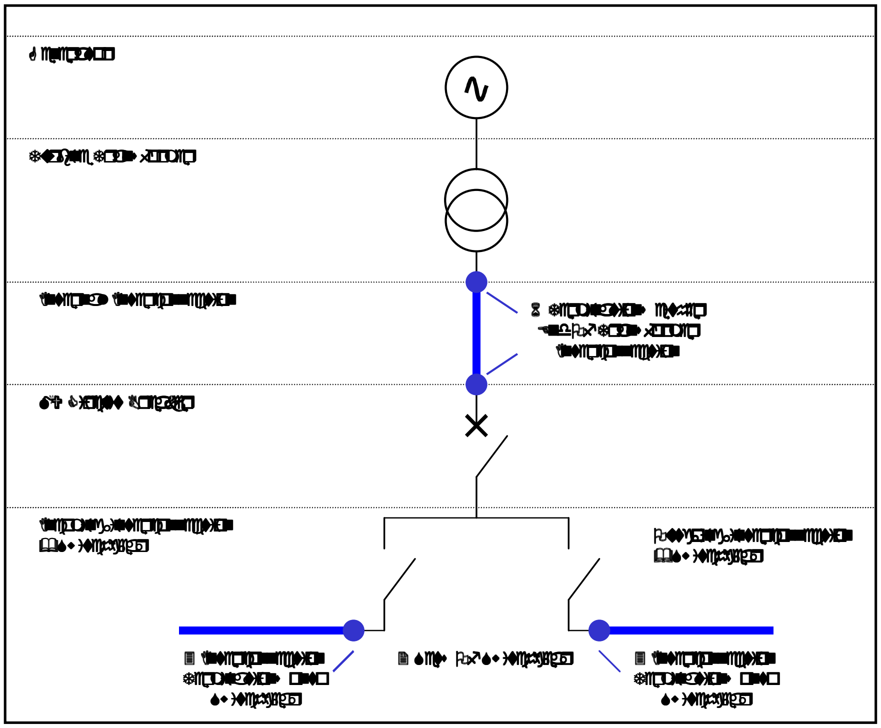

Figure 6: Photo of a RMU arrangement

Figure 7 Fig from page 134 of report F

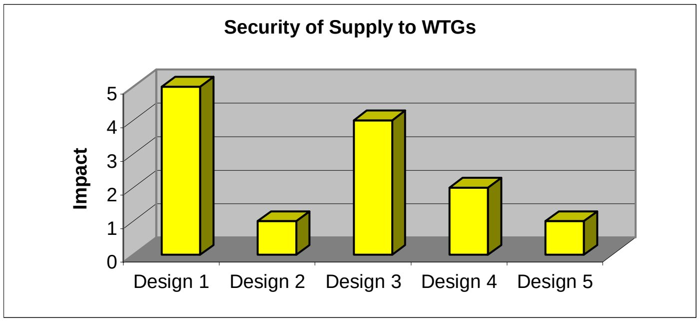

Table 1 Failure Rates for a typical Wind Farm

Component	Number of Failures in 20 year life of Wind Farm	
	Radial Network	Looped Network
Array Cable	3.09	3.35
Shore Link Cable	3.12	3.12
MV Switchgear	0.24	0.74
Terminations	2.98	2.98

Table 2 Cost of Lost Revenue for Failures in a Radial Wind Farm Network

Component	Number of Failures in 20 year life of Wind Farm	Lost Revenue / Fault €k	Total Lost Revenue €k
Array Cable	3.09	210	650
Shore Link Cable	3.12	630	1966
MV Switchgear	0.24	210	50.4
Terminations	2.98	53	158
Total	9.34		2824