CORROSION

STEEL GOING STRONG

ICCP vs GACP

Comparing different protection methods for Offshore Wind Farms

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WHITE PAPER

Offshore Wind

Introduction

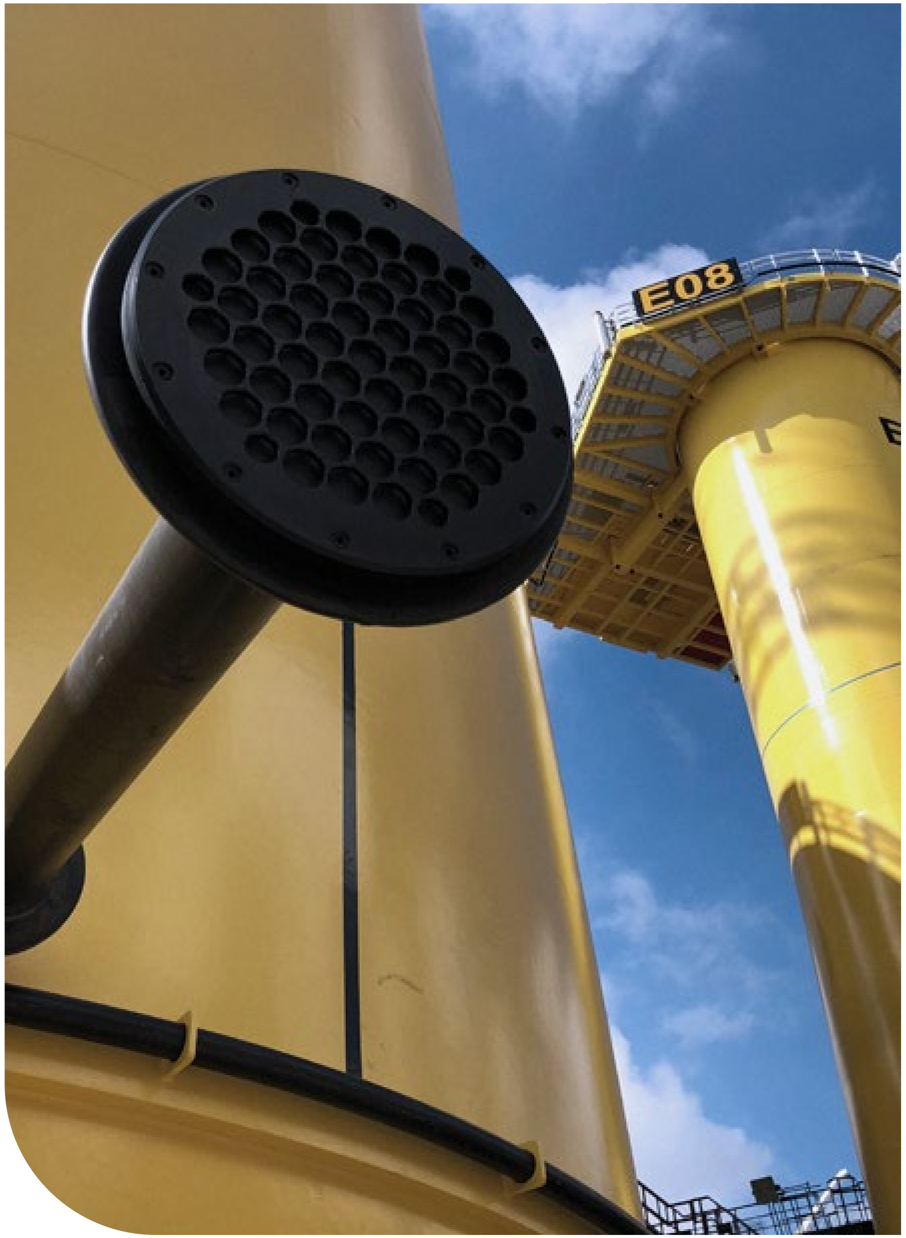
The corrosion of metallic materials in marine environments—such as the infrastructure in offshore wind farms—has been a problem for as long as people have been utilizing metals in water. This is the reason why corrosion protection mechanisms exist. One of the long-standing ways of protecting submerged metallic infrastructure is to use cathodic protection. While cathodic protection methods have been around for a long time, modern-day solutions are able to implement more effective potential controls and monitoring approaches (such as the integration with SCADA systems) that are highly beneficial for offshore wind environments.

The Need for Cathodic Protection

Cathodic protection is required in certain environments because metals undergo electrochemical degradation. Environments where there is water (e.g., the submerged and buried steel foundations for offshore wind turbines) are particularly susceptible. This is because water typically contains dissolved, charged particles with a net electrical charge (ions). These ions can participate in electron exchange reactions at the metal surface if certain conditions are met.

Oxidation reactions result in the removal of electrons from metal atoms, which become positively charged ions and migrate away from the metal structure (causing metal dissolution). Electrons from this process migrate through the metal structure to sites on the same metal where reduction reactions can occur. These oxidation/reduction reactions are complementary and cannot exist in isolation.

Sites where oxidation reactions occur are turned into an anode and those where reduction occurs become a cathode. The metal does not dissolve at cathodic areas. However, the net consequence of both reactions is metal dissolution. It is important to note that an electromotive force is needed



for current flow and for these oxidation/reduction reactions to occur. This force is caused by an electrochemical potential difference between the anodic and cathodic sites. The potential difference is caused by irregularities in the metal surface, for example, the inclusion of more (or less) reactive alloy components in the metal. This is impossible to avoid during production and it is inherent to most construction metal alloys.

Cathodic protection is a way of preventing this electrochemical corrosion mechanism from happening on metal structures. This is done by eliminating the possibility of anodic and cathodic sites forming by equalizing the potentials across the metal surface to that of the most cathodic area possible (hence the name of cathodic protection). In cathodic protection methods, an anode is connected to the metal undergoing protection. The anode turns the complete metallic structure into a cathode by providing a constant source of electrons and effectively brings corrosion to a complete halt or to an acceptable minimum level. This principle applies for both active and passive cathodic protection methods.

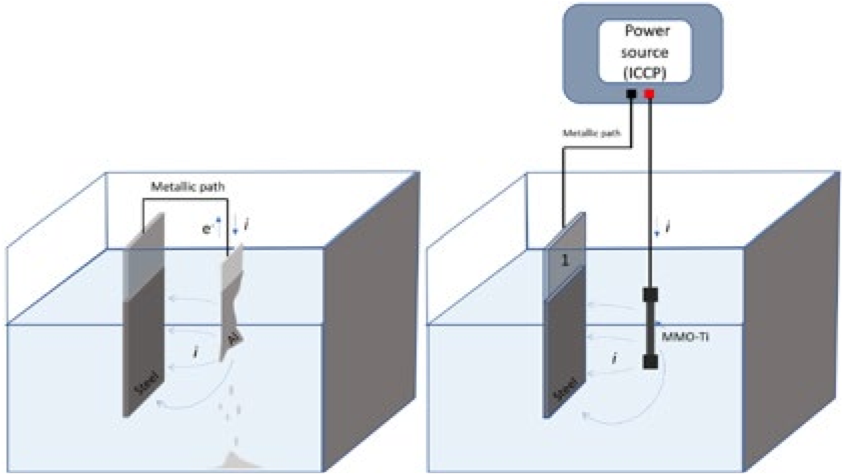


figure 1. GACP vs. ICCP

GACP vs ICCP Methods

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There are two main cathodic protection methods. These are galvanic anode cathodic protection (GACP) and impressed current cathodic protection (ICCP) (Figure 1). GACP is a passive method which exploits the natural tendency of a more reactive metal to become the anode when connected to a more noble metal (the target of protection). This 'sacrificial anode', for the reasons explained above dissolves instead of the cathodically-protected structure. ICCP employs inert anodes that could even be cathodic to the protected structure but are turned into anodes by an external source of current. Special materials that can transfer charge (but not dissolve in the process) are used for this purpose.

In GACP, a sacrificial anode—typically composed of zinc or aluminium alloys—degrades over time because it has much higher electronegative potential than the metal it is protecting, so the oxidative corrosion reactions occur here instead of on the metal. In ICCP, inert anodes (such as those made of titanium with a mixed metal oxide coating) are used and the connection of an electrical current provides a continuous source of electrons. For ICCP systems to work, a direct current (DC) is needed so, a transformer rectifier is typically used to convert the current from an alternating current (AC) into a direct current (DC).

The pros and cons of each method

Every technology or scientific approach has advantages and disadvantages, and cathodic protection is no different. For example, GACP is a well-established method that is known for being reliable in offshore environments, is much simpler in terms of technological setup, and is useful for setups where it is not feasible or sensible to attach an external electrical current. GACP systems are also self-regulating and the current can change to meet the local environment so that the metal structure is always protected. However, the degrading nature of the sacrificial anodes means that a larger mass of anodes needs to be installed for the total design lifetime and the installations take up more space. The additional weight can be substantial and impose significant mechanical stress on the steel foundation. To compensate for this, foundations need to be larger and contain more steel. All these factors increase the running costs in the long-term.

ICCP, on the other hand, offers the same or even a higher level of protection as GACP but it requires fewer anodes, does not suffer from significant material degradation, takes up less space, and ultimately costs less in the long run. While you do need to install a transformer/rectifier unit to convert AC power to DC, the financial and environmental benefits tend to be greater with ICCP. From a usability perspective, the main advantage offered by ICCP systems is control and monitoring. This means that the level of corrosion protection can be remotely monitored, controlled and adjusted if necessary. All this by the use of specialized computer networks such as SCADA.

Environmental Considerations

Naturally, the dissolution of an anode over time when providing cathodic protection has some inherent issues from an environmental perspective. Many wind farms are offshore, so the metallic infrastructure being protected is in a marine environment. Therefore, the removal of an anode (whether it is zinc, aluminium or another metal) can cause the metallic ions to leak out into the local marine environment (Figure 2).

There are some key issues with long-term dissolution of sacrificial anodes into aquatic environments. As the metals break away from the sacrificial anode, they stay in the water (increasing the local concentration) until they reach a saturation point and sediment/complex with other ions. Some of the metals used in sacrificial aluminium alloyed anodes, such as zinc, can easily enter the food chain from ocean environments.

Studies have shown that the levels of zinc in harbours—where there are sacrificial anodes present—can be up to 50 times greater than the natural levels and 5 times above the levels considered toxic. Aside from the potential of induced toxicity into the food chains, higher levels of metal ions (aluminium or zinc) can also

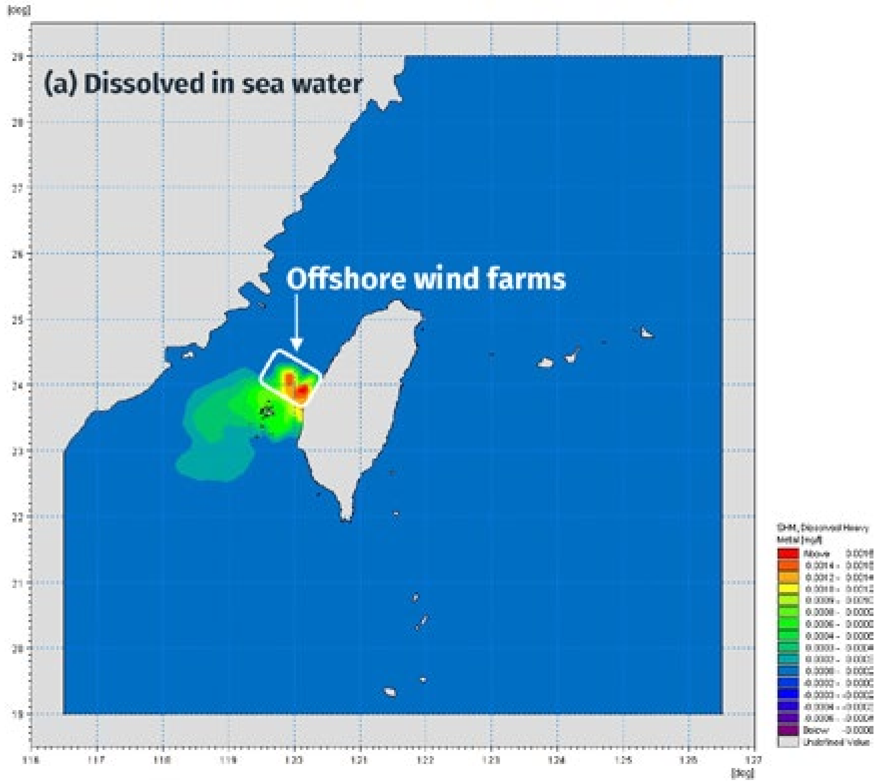

figure 2. Two-dimensional model prediction of aluminum anode dissolution patterns from an offshore wind farm

interfere with the natural pH and salinity levels of aquatic environments. As the natural ecosystem is delicately balanced, such changes can affect different ecosystems in a negative way.

ICCP, on the other hand, is much more environmentally friendly and is harmonious with the sustainability goals expected of a green energy source. Aside from the removal of leaking metal ions into local water systems, less space and fewer anodes are needed for ICCP installations. Environmentally speaking, in the long-term, less transportation and material is required for ICCP installations, reducing the carbon footprint and cost compared to GACP.

Conclusion

Overall, both methods are known to be comparable in terms of the protection they provide to foundations such as monopiles, jackets and floating structures in offshore wind farms. While GACP for relatively small structures can be fully installed onshore, large foundations require the onshore assembly of huge 'anode cages' which are installed offshore. Furthermore, electrical connection must be made between these anode cages and the foundations using divers or remote operated vehicles (ROV). The level of protection can only be measured through dedicated offshore measurements, which need to be made regularly also using divers or ROVs. This implies a significant maintenance cost. By comparison ICCP is more technologically complex, but a lot of the offshore work can be avoided, taking advantage of the continuous data flow provided by the SCADA system. This enables ICCP to be more cost-effective in the long run and is a much more environmentally friendly protection solution.

If you want to find out more about protecting wind farms in a sustainable way, our specialist team would be happy to provide further information.

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