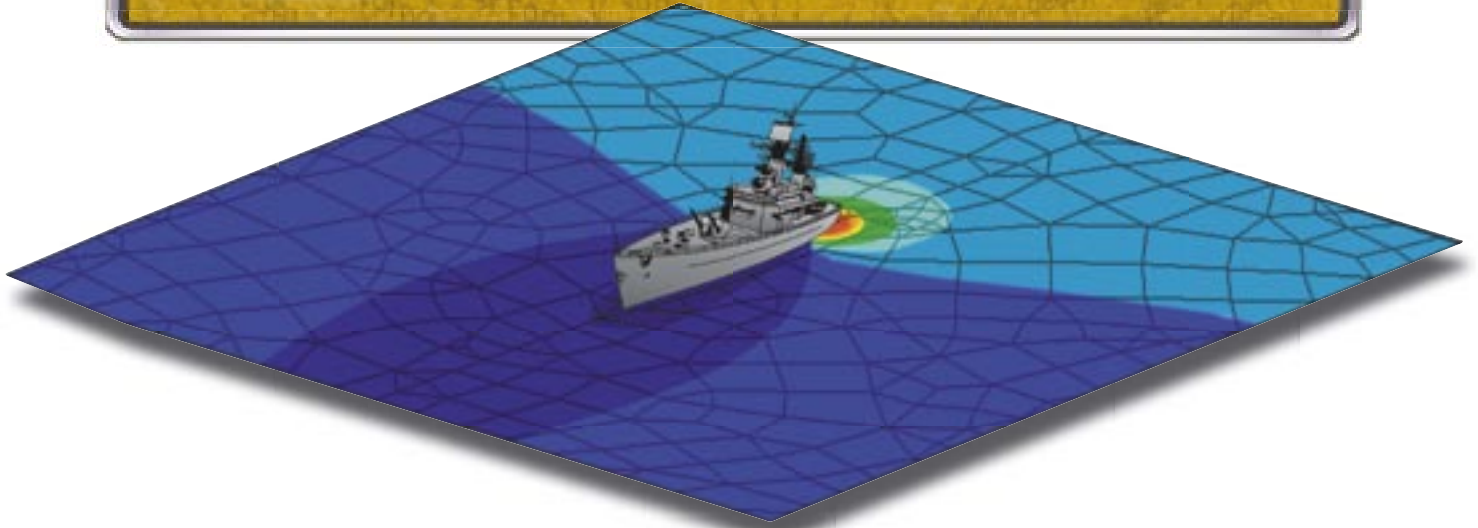




Corrosion Related Electromagnetic Signature Prediction



The design of a cathodic protection system is of great interest to defence organisations not only to ensure the integrity of the vessel, but because it contributes to the electric and magnetic signature of the vessel.

This paper introduces the suite of BEASY modelling tools which provides a comprehensive solution to predict, optimise and manage corrosion related signatures.

Signatures

Electro magnetic signatures are playing an important role in the detection of naval vessels and in the fusing of intelligent mines. The static electric signature is the electric field associated with the DC corrosion or cathodic protection current which flows through the sea water around a vessel. This is sometimes referred to as the Underwater Electrical Potential or UEP. The corrosion related magnetic (CRM) field is the coupled magnetic field caused by the corrosion related electric currents flowing in the sea water between the anodes and the ship hull.

It is important to note that UEP and CRM signatures exist even in the absence of a cathodic protection system. They are caused by the galvanic potential differences

between the metallic structures in contact with the sea water. For example, the relative position in the electrochemical table of steel and bronze provides a sufficient driving potential to create an electric field.

In order to control the signatures and to preserve the integrity of a vessel it is essential to be able to predict the impact of the design and operation of the CP system on the electric and magnetic fields.

BEASY

BEASY is widely used by defence organisations worldwide to predict the performance of cathodic protection systems and to minimise the associated signatures. BEASY works by modelling the electrochemistry on the

metal surfaces and the electric fields in the sea water surrounding the vessel using the boundary element method. In applications where the control of the ICCP system is to be modelled, the simulation also includes a model of the control system (e.g. PID).

The BEASY corrosion and magnetic field software provides, in one detailed model, an integrated approach to predicting the:

- **Performance of the ICCP system**
- **The corrosion related electric field**
- **The corrosion related magnetic field**

Benefits

- An integrated approach to the prediction of corrosion related electric and magnetic fields as well as the effectiveness of ICCP systems.
- The software provides automatic optimisation tools to aid the search for the optimum design and operation of ICCP systems.
- The impact of small changes to the geometric design, coating condition, damaged areas, location of anodes and reference cells etc. can be assessed.
- A full BEM solution is provided whose accuracy is superior to dipole type models as the three dimensional electric fields are captured, e.g. changes to both vertical and horizontal position of the anodes can be assessed.
- Design concepts can be evaluated quickly using the concept modeller based on a dipole type model.

The BEASY Signature Management System

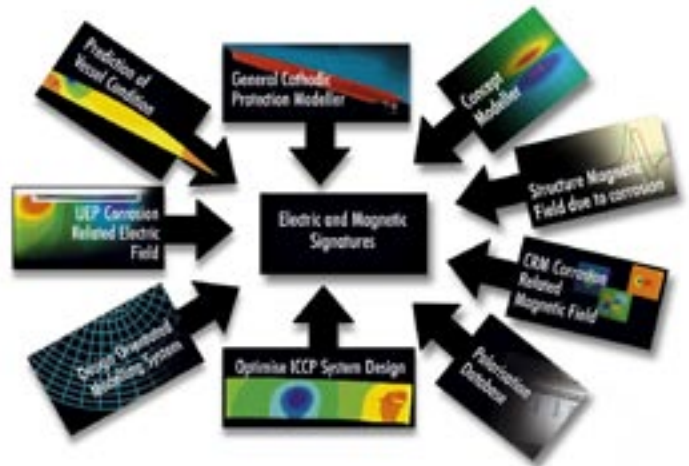


Figure 1 Overview of the components in the BEASY Signature Management System

BEASY provides a comprehensive easy to use system to predict the performance of cathodic protection systems and the associated electric and magnetic signatures. The components of the system are described in detail below.

BEM Detailed Modeller

The BEM detailed modeller is the core of the system as it enables vessels and their surrounding environment to be modelled.

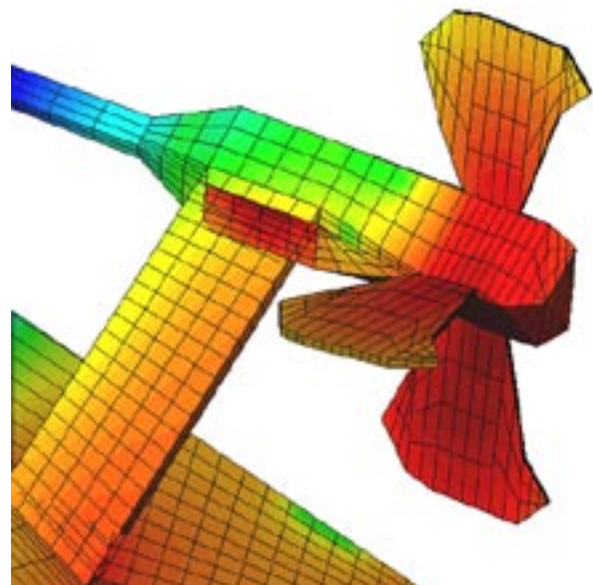


Figure 2 Model showing the elements on the metal surfaces

The model is based on the Boundary Element Method, a mathematical modelling method which simulates the electric and magnetic fields flowing through the sea water, sea bed etc. Incorporated in this model are the equations which describe the electrochemical reactions which take place on the metallic surfaces such as the hull of the vessel or the anodes. It is called a detailed modeller because a vessel can be modelled with practically any level of detail required by the user.

A model is constructed either importing data from a CAD system or creating the geometry within the BEASY system. The next step is to create the element "mesh". The elements are used to describe the surfaces of the vessel and its surrounding environment such as the sea and sea bed. Figure 2 shows part of a model of a vessel including the propellers, shafts, rudders etc. Each of the rectangular patches represents an element which describes a small part of the vessel surface in contact with the sea water. Assembling all these elements together enables a model of the whole surface of the vessel in the sea to be created.

The elements not only describe the shape of the vessel, but they also identify the type of material the surface is made from. Therefore, the elements on the vessel hull will be typically given the property of steel and the propellers NAB, for example. In this way, any number of materials can be included in the model and protective coatings can also be specified on the elements.

The electrochemical behaviour of the metal surfaces is described by Polarisation data which can be specified by the user or selected from the system polarisation database. Each element can have its own polarisation properties.

The properties of the surrounding sea and sea bed are also described by specifying the conductivity or selecting values from the built-in library of values.

BEASY can solve any Galvanic system. It is not strictly necessary to define anodes as the system is capable of solving situations where there are at least two metals in the model. However, when modelling vessels protected by cathodic protection systems, the final step is to add the anodes (Sacrificial and/or ICCP) to the model.

The software then solves the systems of equations representing the electrochemical behaviour on the metal surfaces and the current flow through the electrolyte. The results of the simulation include the potentials and current densities on the metallic surfaces and the electric field in the sea water surrounding the vessel. This can be displayed using the visualisation software provided with the system in the form of contours displays, graphs etc.

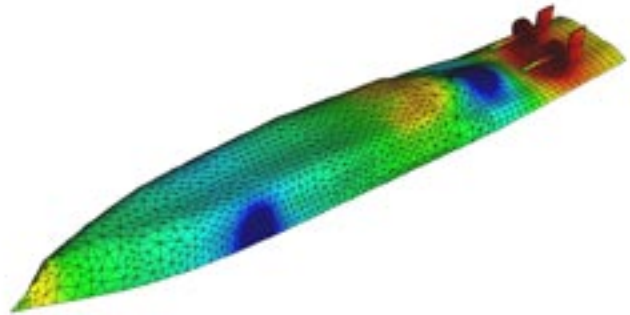


Figure 3 Display of the protection potentials on the surface of the vessel

The model also provides full information on the performance of the anodes, so for sacrificial systems, the anode life can be predicted and the power requirements of ICCP systems calculated.

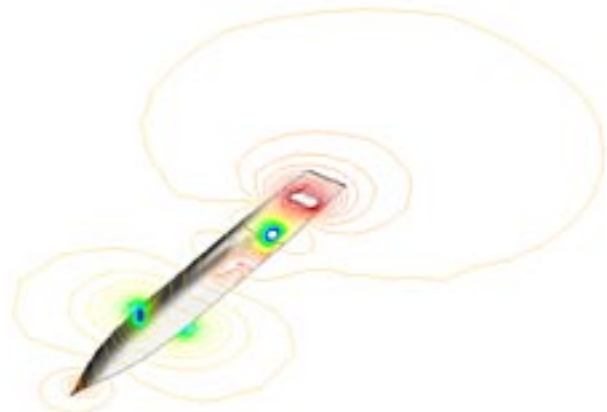


Figure 4 Display of the electric field on the sea surface

Corrosion Related Magnetic Fields

For those interested in signatures, the electric and magnetic field surrounding the vessel is required. The system can provide full information on the electric field in the sea water sea bed etc, plus the magnetic field in the surrounding environment.

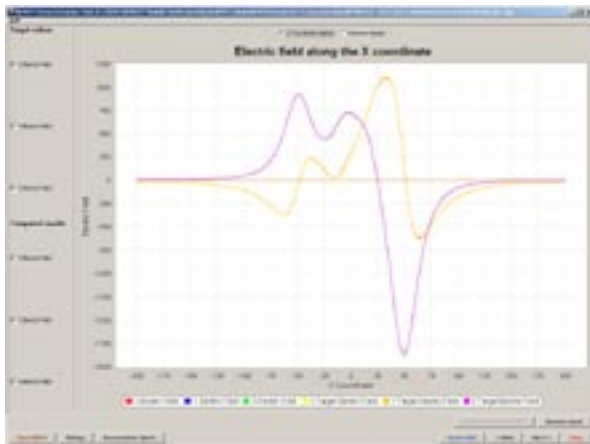


Figure 5 Predicted Electric and magnetic signatures below the vessel

There are a number of ways this data can be displayed. In Figure 4, the signature below the vessel is displayed in the form of a graph.

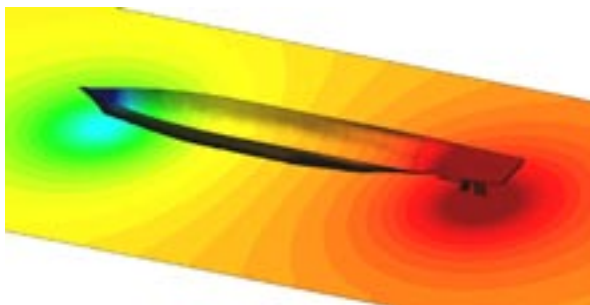


Figure 6 Predicted Electric Signature Contour Plot below the vessel

There is also a general tool provided to display contours of the electric and magnetic fields on planes for example below the vessel. These are called "display planes".

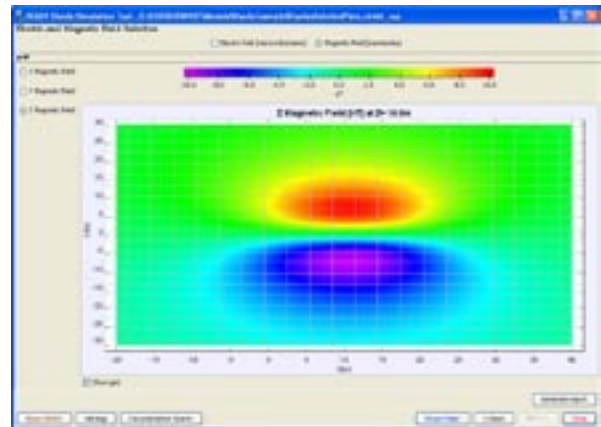


Figure 7 Magnetic field below the vessel as shown on a plane 10m below the surface

Polarisation Database

A key to successful modelling is the data used to describe the electrochemical behaviour of the material in the model. This is normally referred to as the "polarisation data" which describes the non linear relationship between the potential difference and the current density on the metal surface. (Note the potential difference is measured between the metal and the electrolyte using a standard electrode, e.g. AgAgCl). The system provides a convenient way to retrieve and use polarisation data stored in the system database.



Figure 8 Sample polarisation data

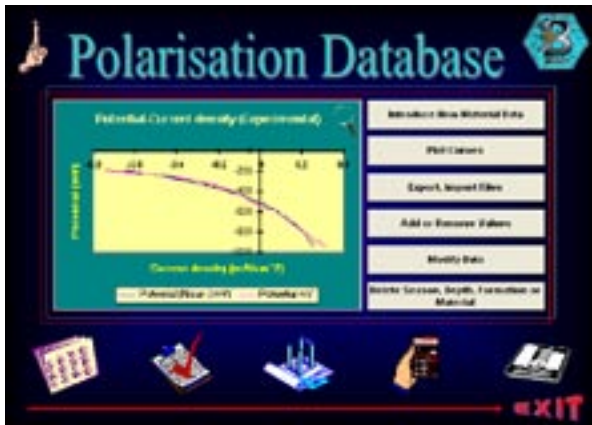


Figure 9 BEASY Polarisation database

BEASY GID

A variety of tools can be used to build the geometric model and create the mesh. The most recent component added to the BEASY system is BEASY GID.

BEASY GID is compatible with most CAD and solid modelling formats which enables geometry already created, to be easily imported and quickly automatically meshed using the powerful meshing tools. The system also provides geometry generation tools to enable new models to be created or imported models modified.

Powerful visualisation tools are also provided to view the model and create reports on the results obtained from the simulation.

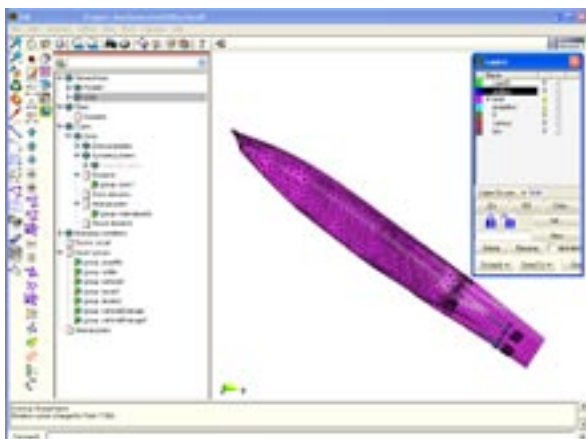


Figure 10 BEASY GID can be used to build and visualise the results

BEASY Solver Wizard

The BEASY Solver Wizard provides a spreadsheet style interface to enable the specification of materials, conductivities, etc. without the need to make changes in the BEASY Visual Interface. Therefore, the tasks of building the model geometry and mesh can be separated from the decisions related to the location of damage areas, polarisation properties to be used, coatings used and their breakdown factors, anode materials and ICCP anode characteristics.

The wizard also guides the user through the process of specifying the model properties and provides interactive help and tutorials to ensure the user does not waste time finding the information needed.

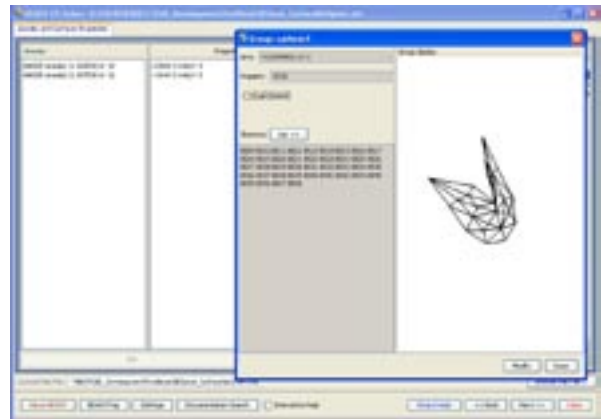


Figure 11 The BEASY solver provides complete control over the data used in the model and guides the user

Another useful feature is the monitoring of models while they are running and verification of results after the completion of the simulation. A monitoring tool is available to display the progress of the simulation and in particular the convergence of the non linear solution.

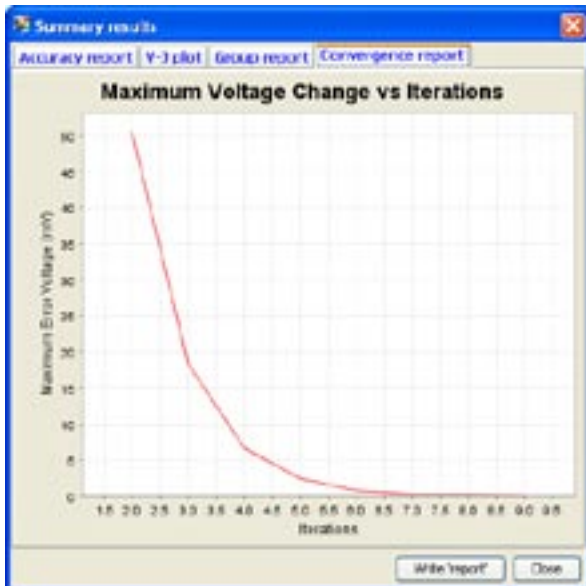


Figure 12 The Convergence of the solution is monitored in real time

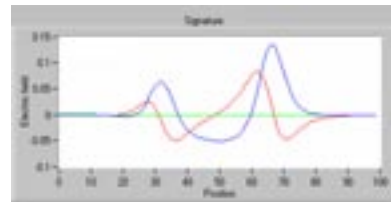
A key test of a successful simulation is that all the results accurately follow the polarisation data specified. This information can be quickly displayed using the solver wizard and any problems identified. This is just one of the powerful features of the wizard, other capabilities include:

- Summary for each surface of the min, max, and average potentials plus the total current and current densities
- Quick display of contours and graphs of electric and magnetic field
- Quick display of groups of elements representing objects in the model

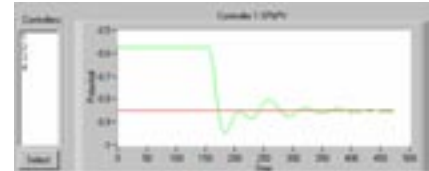
ICCP System Simulation

A powerful feature of the system is the ability to predict the real time response of ICCP systems by coupling a model of the ICCP controller with the model of the complete vessel (i.e. the model of the metallic vessel and surrounding sea water).

This tool is particularly useful for engineers who need to investigate the optimum control set up to avoid instabilities in multi zone systems. Typical applications include the simulation of switch on conditions, controller failure and the investigation of optimum reference electrode locations.



Real time signature display



Real time simulation of switch on

Optimisation

The optimisation module is a powerful tool which can automate many of the tasks required when investigating signatures. To use the software a BEASY model is constructed in the same way as that for a normal simulation. The additional data required are the "objective" of the simulation, the "constraints" and the "design variables".

An example of an objective could be to minimise the magnitude of the electric field a certain depth below the vessel, or it could be to find the ICCP anode settings to achieve a specified potential at a reference electrode. Constraints could be to ensure that the potentials on the vessel are maintained within a range to ensure protection. Finally the design variable is the variable which can be changed to achieve the objective. Typically this is some property of the anode such as its current output or position.

Once set up, the software automatically searches for the best solution which satisfies the constraints.

Another application of this tool is to perform an "inverse" analysis. For example, a vessel has damaged areas of coating but their size and location is unknown. What is known, however, is the data from the ICCP system and the potential readings from the reference electrodes. Therefore, we can use the optimisation software to find the damaged areas by setting our objective to match the reference electrode potentials and making our design variables the location and the extent of the damage. If sufficient data is available, the software can successfully determine the location and extent of the damage.

This type of study can also be performed using data from sensors in the sea, rather than the reference electrodes on the vessel.



Figure 13 Predicted areas of damage on the vessel using the inverse analysis

Structure Magnetic Field

It is important to remember that the corrosion related magnetic field surrounding a vessel is caused by two sources. The CRM predicted from the BEM modeller only considers the fields generated by the current flowing through the sea water, sea bed etc. surrounding the vessel. However, there is another component caused by the corrosion currents flowing back through the internal structure of the vessel. Note this is not the same as the ferromagnetic fields.

The BEASY structure magnetic field software calculates this additional magnetic field using the data from the BEM model. The BEM model provides details of how much current is flowing into and out from each element on the vessel.

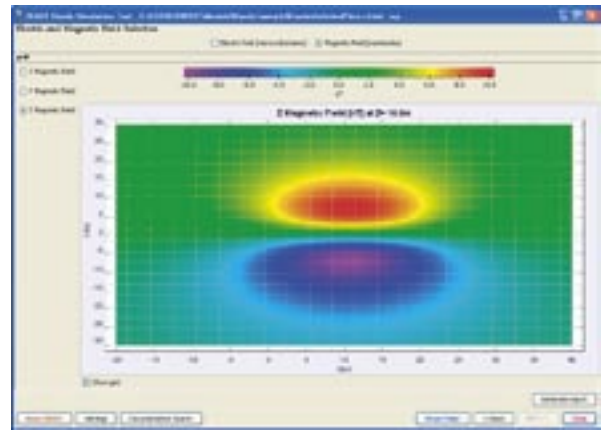


Figure 14 Predicted magnetic field due to corrosion currents flowing through the vessel structure

Concept Modeller

Up to now, the simulations have been performed using the detailed BEM models. However, in some cases a quick conceptual model is required to explore design options and solutions. This is provided in the BEASY Signature software by the Concept modeller. The Concept modeller is based on a dipole type solution which represents the key elements in the CP system as a series of sources and sinks which represent the anodes and the locations on the vessel surface which receive current from the anodes.

The Concept modeller enables all the parameters in the model to be quickly changed (e.g. depth, conductivity, anodes, damaged areas etc), a new prediction made, and the electric and magnetic fields visualised.

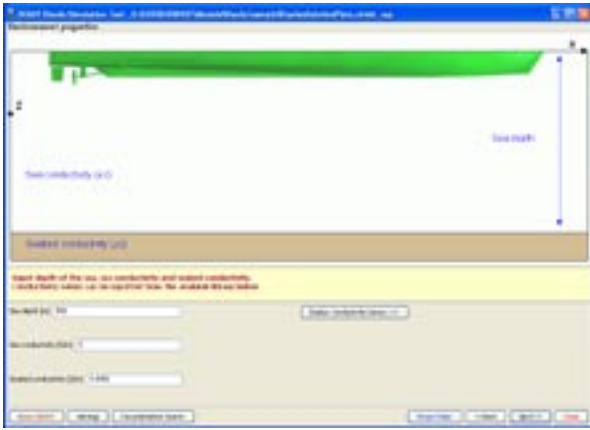


Figure 15 Concept Modeller user interface where quick changes can be made to any parameter

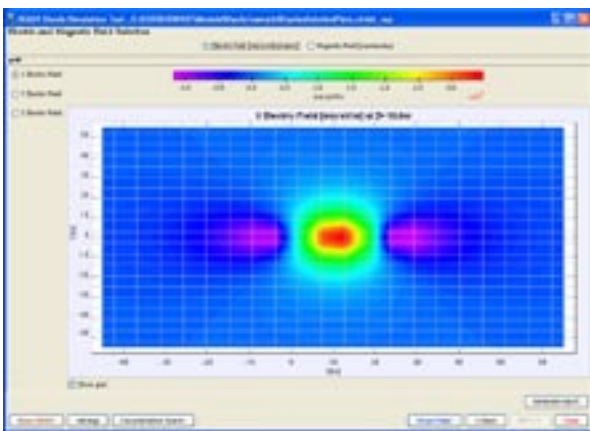


Figure 16 Example display from the Concept Modeller of the predicted electric field 10m below the surface

Characterisation Tool

The Characterisation tool, in some ways, provides a link between the Detailed BEM model and the Concept dipole model. It provides the ability to compute an equivalent Concept model from the results of a Detailed BEM model. This is useful in some circumstances where, for example, you have completed a detailed study and now wish to see immediately, the impact of changing some of the parameters. Obviously this is only an approximate solution but it has the advantage that it is very quick.

Another application of the Characterisation tool, is to interpret signature or sensor data obtained from ranging. An equivalent model of a vessel which produces the same signature as that measured can be calculated.

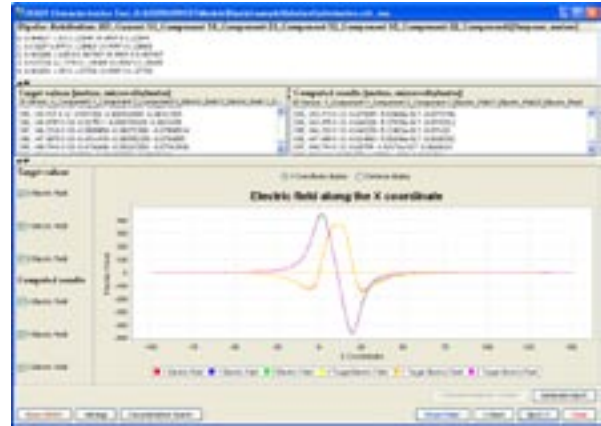


Figure 17 Display from the Characterisation Tool showing the match between the signature calculated from the equivalent Concept model and the input signature

Summary

BEASY provides a comprehensive solution to the modelling of all aspects of corrosion related signatures.

Easy to use tools are available to predict, optimise and manage corrosion related signatures.

BEASY provides both detailed BEM based modelling tools as well as analytic concept models.

The system is capable of studying static signatures as well as ELFE behaviour.



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