

Improving Integrity Management Decision Making Using Automated Calibration of Model Predictions From Cathodic-Protection (CP) Survey Data

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ABSTRACT

The actual protection provided to structures by Cathodic-Protection (CP) systems will often be different from that predicted by design calculations. This is for various reasons, including for example coating degradation at a rate different from the accepted standards and practices, assumed environmental conditions not being representative, etc. In addition, structural or CP system changes and retrofits may have been made. It is important, therefore, that models of the structure, used to predict the current and future protection provided by the CP system, are recalibrated as survey data become available during the life of the structure.

Because the models used to simulate CP systems are non-linear and time-dependent, manual calibration processes can be difficult and time-consuming. Additionally, with the development of new sensor technologies providing the opportunity for more real-time CP data, there is a need for an automated approach to calibration.

A new approach has been developed to automate the process of model calibration and evaluation of predictions as new data from the CP system becomes available. The proposed approach utilises an integrated scientific computing platform including the CP model and relevant analytical tools to perform four key steps of (1) mapping the model parameters to the inspection data, (2) model performance

validation, (3) reduced-order modelling that includes developing approximation model and (4) optimisation-based parameter updating.

In this paper, a case study is presented for a marine structure for which modelling has been used to predict the protection potentials over the life of the structure.

Keywords: Corrosion, Corrosion Data Management, Digital Twin, Cathodic Protection

INTRODUCTION

The aim of any digital transformation of integrity management and in particular corrosion control is the improvement of communication efficiency, planning efficiency and maintenance efficiency. Key issues are predictive maintenance and clarity of the information available so engineers can make informed decisions. Therefore it is not just a question of collecting more information but also the way that information is used and shared with the decision-makers.

The development of advanced computational models capable of predicting the level of protection provided by cathodic protection systems and how this changes over the life of the asset has significantly improved the information available to the corrosion/integrity engineer^{1,2}. Typically, this modelling approach has been used as part of the design process to optimize the protection provided to the structure. However, in recent years the benefits of integrating modelling into the management of long term integrity have been understood and have enabled unplanned downtime and failures to be reduced. In this approach, the digital twin model is continuously calibrated with the data available from routine inspection surveys and monitoring devices to provide a 3D virtual twin of the current status of the asset to the engineer responsible for integrity management. The digital twin provides a clearer understanding of the protection provided to the asset and can be used to make predictions of the present and future protection of all parts of the structure^{2,3,4}. For example, the engineer can use the software to systematically monitor the differences between the model predictions and survey data to identify anomalies and to provide early identification of problems that will require mitigation.

The task of calibrating the model is however not straightforward as surveys are frequently conducted at irregular intervals, the data are often not measured at the same locations and in many cases, only a small number of data points are available at a particular time.² Therefore the manual approach to calibrating the model can be time-consuming and result in significant uncertainty. There is also a need to have a systematic measure of the accuracy of the “calibration” between the model and the real asset as the data changes over time.

In this paper, an approach is presented to automate the calibration process to enable the digital twin to be available to the engineer in a timely manner and with consistent accuracy.

PLATFORM AND APPROACH

The cathodic protection simulation software models the electrode kinetics on the metallic surfaces and the current flow through the electrolyte. The data required by the model includes the model geometry described by a computational mesh, the electrolyte properties such as the conductivity, the polarisation properties of the anodes and the metal structure and the properties of the coatings typically expressed in the form of a coating breakdown factor. These parameters are used within the numerical model (BEASY⁽¹⁾ based Cathodic-Protection Modelling) which in this case is based on the Boundary Element Method (BEM). ¹ The process of model calibration by parameter adjustment/estimation is usually performed manually by engineers utilising their expertise and field knowledge to set the material-related parameters i.e. polarisation behaviour between surface material(s) and the electrolyte (seawater) resistivity. This involves the comparative analysis between the model predictions and the inspection

⁽¹⁾ BEASY Tradename

survey measurements to determine if the model prediction matches the asset data within some acceptable threshold, then adjustment of the model parameters is made if necessary, to bring the prediction data into an agreement with the inspection data.

An additional factor complicating the calibration is the number of parameters to be varied during the domain space exploration method of parameter estimation. More parameters increase the computational cost as many cases have to be simulated particularly for models of large complex assets.

Enabling Digital Twin for a CP system.

The virtual replica of an existing physical counterpart recognised as Digital Twin (DT) in recent years is required to have self-adaptive characteristics to provide robust prediction throughout a lifetime.³ However, the implementation of the DT concept to offer benefits to real-world problems in most domains is challenging and still in its infancy.⁴ In the context of CP, a digital twin is a robust computerized virtual model that simulates the physics of galvanic corrosion and the features of a cathodic protection system to ultimately provide a detailed view of the present level of protection, but also to forecast the future levels of protection.² Similarly to other domains, there is a need for an automated approach to the calibration and adaptation of the digital twin during the operational phase of the CP system, during which material degradation, anode depletion and retrofits frequently occur during the assets life. Moreover, with time variation of parameter values for different spatial positions over the structure might arise, which is another vital aspect inducing uncertainty in predictive performance that DT should be capable of dealing with throughout the lifecycle of the physical Twin.

Sapkota, et. al propose an integration of the simulator and scientific computing software as an approach that facilitates the end-to-end automation of a CP system simulation within DT.⁵ Utilising this integrated approach this paper will discuss the approaches for timely calibration/adaptation of a simulator-based CP model, therefore providing a path to enable a self-adapting CP model which can be ultimately referred to as Digital Twin. The work also incorporates a method to address the aspect of parameter variability arising with time to the parameters due to different environmental and loading conditions within the same system.

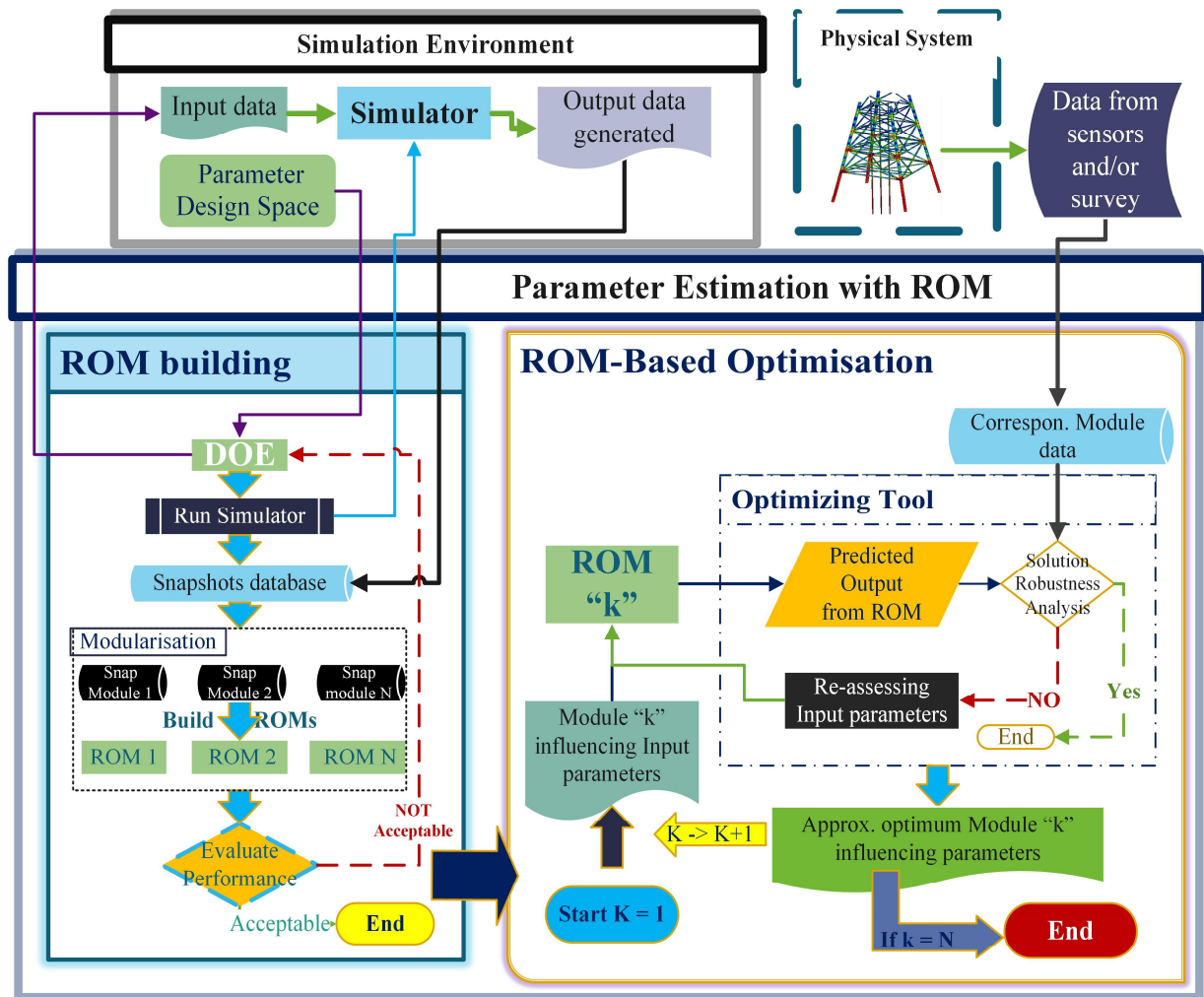


Figure 1: Module-wise Parameter estimation with Reduced-Order-Modelling for Simulator (physics-based) Cathodic-Protection model

The approaches for automating the real-time calibration and/or adaptation together with its performance evaluation for the CP system are described as follows:

1. Domain Modularisation with Data grouping

CP inspection data are normally obtained from measurement at a few feasible locations on the asset. These data are used to infer the general level of protection provided to the asset, and also to compare with model predictions to identify anomalies and calibrate the model when required. The data position distributions and their variability are crucial factors to be considered to avoid reaching the wrong conclusion about the model performance.⁶

When multiple materials-related parameters are involved within the model, the sensitivity of the inspection data to the parameters will frequently vary with the measurement location. The reason for the modularisation of the structural model is to find the appropriate parameters that influence the response data in each module. In other words, modularisation splits and maps the inspection location response data with the input parameters based upon the sensitivity of the parameters to the module response data. This not only benchmarks the data dependency for parameter estimation but also finds the best calibration subset of data for the selected parameter(s).