

The Virtual Corrosion Engineer Project for Soil Side Corrosion Prediction and Cathodic Protection Status Monitoring

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ABSTRACT

Large-scale onshore oil and gas processing facilities typically include a wide range of equipment (pipelines, tanks, in-plant piping etc.) that are potentially exposed to soil-side corrosion, and this threat is usually mitigated by a combination of external coatings and cathodic protection. The status of the cathodic protection is then monitored using a variety of routine measurements, the results of which are then checked against industry standard requirements and reported as key performance indicators for the effectiveness of the corrosion mitigations. It is also possible to estimate the soil-side corrosion rate of the at-risk equipment using corrosion models which can be used as the basis for future inspection and maintenance planning. The Virtual Corrosion Engineer (VCE) project automates the handling, analysis, and visualization of the monitoring data and presents real time Key Performance Indicators and Corrosion Rate predictions in an interactive web-based dashboard.

This paper provides an overview of the VCE system for analysis of Cathodic Protection monitoring data and predictions of soil-side corrosion rates. This includes automating the ingestion of the data, generation of the Key Performance Indicators (KPI) and creation of real-time corrosion rate predictions. This paper describes some of the challenges and solutions from this project, as well as comparison of the model corrosion rate estimates against design expectations and inspection results.

Key words: Corrosion Control, Cathodic Protection, Risk Based Inspection (RBI), Simulation and Modeling, Underground Corrosion

INTRODUCTION

Corrosion is a ubiquitous phenomenon, which can have massive impacts on the functioning of industrial assets. The threat of corrosion is exacerbated in situations where regular corrosion inspections are difficult. The Virtual Corrosion Engineer (VCE) Project within Shell⁽¹⁾ is intended to offer a solution to this problem by automatically assessing the corrosion rates and threat levels in assets due to a variety of corrosion mechanisms. The VCE system has been deployed in an asset progressively since 2019. In this paper, we present the VCE approach to predict and manage the damage caused by the mechanism of

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soil corrosion in a large-scale industrial asset. In the sections below, we shall provide a high-level overview of the VCE project and the VCE approach for estimating soil corrosion damage.

The VCE Project

The VCE project is intended to be an automated tool which predicts and manages corrosion threats and creates additional availability of assets. VCE blends data science and domain science relevant for the corrosion mechanism being monitored to produce live and reliable predictions of corrosion related damage. The VCE project moves the asset towards being an ‘asset of the future’, i.e., an asset that is highly automated, which optimizes itself and maximizes equipment performance, and has improved availability. The VCE project is intended to monitor the risk of all possible corrosion damage mechanisms everywhere in the asset, for every equipment in the asset, at all times, in order to prevent unplanned downtime and the losses incurred.

VCE Approach to Soil Corrosion

The asset in consideration hosts several carbon steel equipment which are in contact with soil. These include underground sections of fire hydrants (field pipe connecting the above ground fire hydrant section to the buried non-metallic fire water distribution system), buried piping, pipelines that carry fluids and products to and off the plant, and floors of storage tanks. These equipment are prone to soil corrosion, which if unchecked can cause of unexpected plant downtime and loss of production. The equipment prone to soil corrosion are protected by applying effective protective coatings and adequate Cathodic Protection (CP). It is vital that the asset monitors the CP levels for all at-risk equipment to assess the soil corrosion threat.

In the asset under consideration, this monitoring has historically been performed monthly or bi-annually depending on equipment type. This monitoring data (which includes CP potentials) were documented in Excel files since its inception. Over time, this has led to the accumulation of thousands of Excel sheets containing historic monitoring data. As the data accumulates it becomes increasingly difficult to generate meaningful quantitative insights from this wealth of data, since they are stored in Excel sheets with varying designs. Given that the asset has a large number of test points, and new measurements being recorded every month (since there are many equipment being monitored monthly), the Key Performance Indicators (KPI) also needed to be generated monthly to track the status of the CP systems that defend against soil corrosion. Moreover, corrosion rate calculations should also be done periodically to assess any corrosion related threats to critical equipment. Obviously, doing these computations every month is an arduous albeit unavoidable task.

VCE intends to optimize this process by automatically ingesting the monitoring information from PI (Process Information) tags¹, generating CP KPI, and calculating the corrosion rates for all equipment using engineering models of soil corrosion and the inspection data. By taking the analysis process off the engineer’s hands, the VCE system enables the engineers to focus on decision-making based on the live insights generated regarding the status of the CP system. The Corrosion Rate predictions along with the KPI dashboards enables engineers to easily identify soil-side corrosion threats early. This empowers the engineers to plan the maintenance and repair strategy optimally & proactively which in-turn reduces the overall risk profile of the site. Melding digitalization with CP monitoring and soil corrosion assessment advances the status quo by enabling the detection and mitigation of corrosion threats quickly, early, and effectively.

This paper presents an overview of the VCE system for analysis of CP monitoring data and estimating soil-side corrosion rates. The corrosion rate calculations are based on accepted models within Shell and API⁽²⁾ 581² & API 651.³ The challenges and solutions from this project, as well as comparison of the

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model corrosion rate estimates against inspection results are described in the following sections. The approach used to automate the CP analysis process to generate live, interactive KPI dashboards and corrosion rate predictions will also be outlined.

BACKGROUND

Overview of VCE Approach

VCE works by connecting the equipment monitoring data that streams from the site with the relevant corrosion models upfront, so that protection statuses and corrosion rate calculations for various equipments in the system is performed automatically at predefined frequencies (hourly / daily). The various sources of data are integrated into the predetermined set of calculation steps in VCE so that the VCE system knows how to handle new data that comes in. The data input into the system could be from:

- **PI data:** PI (Process Information) data¹ is the live monitoring data for the equipment concerned. For CP systems being discussed here, it is the measured CP potentials that indicate the protection status of the equipment. The CP potential measurements can be acquired automatically or manually, which can then be uploaded to PI servers[†].^{1,4}
- **Inspection Data:** Inspection data in the case of CP systems is the corrosion rates measured during inspections. This can be compared against the predicted corrosion rates to tune the models for better accuracy.
- **Design Data:** This corresponds to the design information such as the design corrosion rate, design life, design temperature of equipment, RBI (Risk Based Inspection) Consequences⁵ etc., which are required for corrosion rate or RBI Criticality calculations.
- **IOW Data:** IOW (Integrity Operation Window) data corresponds to the ranges within which the equipment is intended to operate. In case of CP and soil corrosion, it is the upper and lower limits for effective CP (for example the -850 mV to -1200 mV criteria, see “Cathodic Protection Criteria” section below).

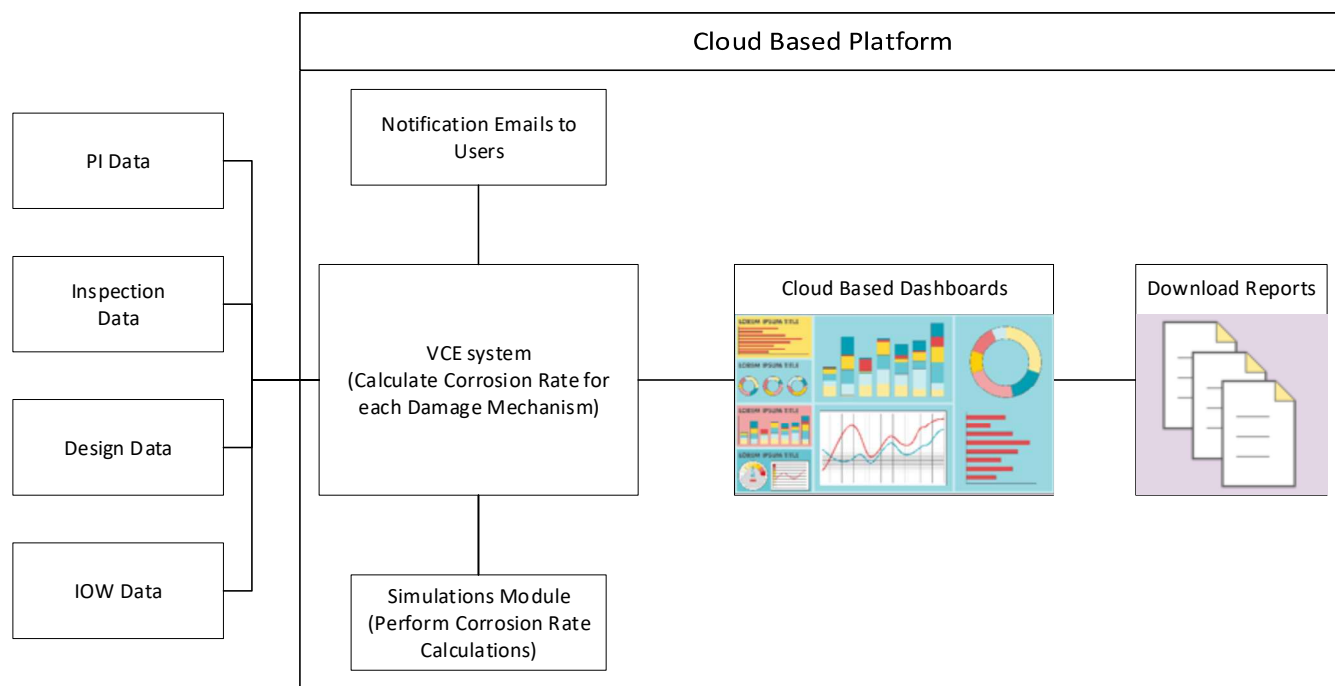


Figure 1: High Level overview of the VCE setup.

As shown in **Figure 1**, The input data is automatically fed at predefined frequencies into the cloud-based platform which hosts the VCE. The VCE system then sends the input data to the right module (the soil corrosion module in this case) for calculating the corrosion rate, protection status, RBI criticality etc. The soil corrosion module then returns VCE the calculation results, and depending on the level of the threat detected, notifications can be sent to the users (based on pre-defined rules for sending notifications). The generated data is also displayed in a web-based dashboard which all users can access. The dashboard is interactive, shows high-level KPI, and could be interactively controlled to see equipment level history of corrosion rates and other measurements. Depending on the choice of the user, the dashboard could prioritize to focus on corrosion rates, the RBI criticalities, the cumulative number of exceedances of the IOW window, or some user-defined parameter indicative of the corrosion damage (in case corrosion rate calculations are unavailable). The user can also generate reports based on the results generated by the system.

The VCE approach to modeling soil corrosion is rather straightforward, since there are existing models for soil corrosion rate calculations, which could be readily used. In the following section, we shall give a brief overview of the soil corrosion mechanism, defenses against soil corrosion and the soil corrosion rate calculation.

Soil Corrosion Mechanism

Soil Corrosion affects all carbon steel equipment that are in contact with soil. As mentioned previously, the asset hosts a significant number of equipment that are either in contact with or buried in soil. This makes soil corrosion a priority for the asset, especially since the soil resistivity tests have indicated that the soil type in the asset is moderately corrosive.

A plethora of factors can influence the rate of soil corrosion, including resistivity, moisture content, dissolved salts, presence of corrosion activating bacteria, pH, oxygen content, stray DC currents etc. Factors such as metallurgy, type and condition of coating, size, temperature, presence of dissimilar metal couples etc. can also influence soil corrosion.⁶

Protection Against Soil Corrosion

Coating.

To protect against soil corrosion, both protective coating and CP are provided to equipment in assets. Coatings provide high resistance to the electrochemical current and effectively prevents corrosion. Coatings also reduces the amount of current necessary for CP. The coatings that are used to protect equipment include: coal tar and asphalt enamels, mastics, waxes, poly vinyl chloride, polyethylene tapes, thermosetting epoxy resins, epoxy coatings etc. Unfortunately, these coatings are not perfect since they develop holidays (discontinuities in coating) and deteriorate with time. Coating damages can be caused by installation, excavation, 3rd parties, chemicals present in soil, bacteriological activity, penetration by tree roots, and thermal and mechanical stress.⁷ CP is hence always applied as a complementary protection to the coating.

Cathodic Protection.

Coatings can protect effectively against soil corrosion for the first 10 years approximately.¹⁰ However, coatings degrade over time and progressively becomes less effective. CP is provided so that we have a second layer of protection when a coating is no longer 100% effective. This makes it crucial that CP is monitored, and that all equipment get adequate CP during their design life. Additionally, if an equipment does not get adequate CP during its life, it is important that the corrosion damage incurred is calculated and threats are identified before failure occurs. Both Sacrificial Anode Cathodic Protection (SACP) and Impressed Current Cathodic Protection (ICCP) are used in the asset.

Cathodic Protection Criteria

For a CP system to be effective, it needs to provide the adequate '(instant) OFF potential' (potential measured with respect to a reference electrode immediately after turning CP off) to the structure or create a certain amount of potential shift from its native potential. According to the site requirements the protection criteria need to be achieved for buried equipment are as follows⁸:

- A negative polarization of the pipe potential in soil or contacting electrolyte, to the range of at least -850 mV (or more negative) with reference to a Cu/CuSO₄ electrode. A further negative polarization of 100 mV is recommended where the soil condition is anaerobic or sulfide reducing bacteria is suspected in the soil.
- A minimum instant OFF polarized pipe potential not more negative than -1200 mV in soil or contacting electrolyte, with reference to a Cu/CuSO₄ electrode.
- In addition to the above limits, a minimum polarization potential a minimum polarization shift (difference between off potential and native potential) of 100 mV (or 300 mV in certain situations)⁹ is also considered as an alternative acceptance criterion for effective CP for tanks.

All equipment having OFF potentials > -850 mV are considered under-protected, while those which have OFF potentials < -1200 mV are considered over-protected. For tanks, if the measured potential of any of the test point of the tank fails to meet both the -850 mV criteria and the 100 mV potential shift criteria (points 1 & 3 above), the tank is considered under-protected.

SOIL CORROSION MODELING

Soil Corrosion – Fire Hydrants, Piping, Pipelines

We use the logic behind the External Corrosion Management (ECM[†]) tool (a tool used within Shell, with some minor modifications which are outlined) for all equipment except tanks that are in contact with soil. The tool was designed for estimation of external corrosion rates of buried piping. To prevent soil corrosion, external coatings are provided as the first layer of protection, and CP is provided as the second layer of protection. These two layers work in conjunction with each other to protect the piping against the corrosion rate that the metal would experience in the absence of these two layers of protection (base soil corrosion rate). Hence, the corrosion rate is calculated using the following parameters:

- Base corrosion rate CR_{base} : CR_{base} is a function of the soil properties.
- Coating effectiveness P_{eff}
- Cathodic protection effectiveness CP_{eff}

Once these parameters are determined, the corrosion rate is calculated as:

$$CR = CR_{base} (1 - P_{eff})(1 - CP_{eff}) \quad (1)$$

The base soil corrosion rate CR_{base} is a function of the soil characteristics.¹⁰ In this work, the base soil corrosion rate is based on the resistivity measurements on the site. The field resistivity measurements put the soil resistivity in the asset under consideration between 1000 – 5000 ohm·cm, which gives a base soil corrosion rate of 0.2 mm / year based on the resistivity versus corrosion rate table¹⁰ (**Table 1**) used within VCE. This corrosion rates shown in **Table 1** are comparable to, but more conservative than what was presented by W. J. Schwerdtfeger¹¹. A comparison of the values in **Table 1** and that presented by W. J. Schwerdtfeger¹¹ are shown in **Figure 2**.

[†] Trade name

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