

**Applying Machine Learning Techniques to Identify and
Predict Behavior of Rectifier and Groundbed State Change**

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ABSTRACT

We explore how rectifier voltage and current measurements can inform pipeline engineers and technicians on the health, performance and operation of their cathodic protection (CP) assets, and predict the future operation of existing and newly installed cathodic protection systems. We leverage years of data from monitoring units installed on CP rectifiers combined with site specific details describing the site and its CP system provided by pipeline operators to train a machine learning model.

The study includes current and historical data from hundreds of unique rectifier locations across Canada which have been historically monitored using a remote monitoring unit (RMU). RMU readings are analyzed and grouped by long term resistance trends. Contextual data is collected for each site. This data describes the cathodic protection relevant details of the site, including details of the pipe, rectifier, groundbed and soil.

A machine learning model has been developed which accepts the contextual data associated with the rectifier and will predict the long-term rectifier resistance trend.

Key words: Cathodic Protection, Impressed Current Systems, Rectifier, Groundbed, Pipeline, Machine Learning, Predictive Maintenance, IoT, Big Data, Artificial Intelligence, Remote Monitoring

INTRODUCTION

Impressed current rectifiers are the backbone of a pipeline operator's cathodic protection (CP) systems. A rectifier's ability to protect a large length of electrically continuous pipeline considerably improves efficiencies and reduces material costs as compared to galvanic systems^{1, 2}. However, like galvanic anodes, impressed current anodes are a consumable asset, and require replacement at the end of their service life to ensure that the rectifier can continue to adequately protect the pipeline.

The CP industry has relied on system resistance, commonly calculated using voltage and amperage data collected from rectifiers, as a leading indicator of rectifier groundbed performance³. However, much of this analysis is performed manually, irregularly, and on a limited data set of few assets, which has precluded the depth of insight that this method has been able to generate for practitioners⁴.

In the recent decades, advances in cellular and satellite communications have enabled remote monitoring of the electrical parameters associated with cathodic protection. This has allowed operators to gather data more frequently and save time by avoiding unnecessary visits to hard-to-reach sites. The next phase in technological improvement of CP system monitoring is analyzing large amounts of remotely gathered data and using machine learning algorithms to make predictions and gain insight from various related datasets⁴⁻⁶.

Using the readings from remote monitoring units, long-term trends and predictions related to the rectifier-anode-pipeline system can be made. Because the replacement of an anode bed can be a considerable capital project, understanding when an anode moves from a steady state condition into a condition of deterioration or failure is a valuable insight for both CP technicians and planning engineers as they establish short- and mid-term capital and operating budgets.

In this paper, a method for classifying the long-term resistance trends on an impressed current cathodic protection as measured by hundreds of RMUs across Canada is presented. After classifications of long-term trends are made, the classification features are joined with location specific data of the soil, pipeline, groundbed, anode and rectifier. A classification algorithm is trained to predict long-term trends using these features alone, without the need for resistance readings.

EXPERIMENTAL PROCEDURE

For over a decade, Mobiltex has been collecting data from impressed current cathodic protection (ICCP) rectifiers. The most typical installation consists of a Remote Monitoring Unit (RMU) connected to a transformer rectifier outputting near constant voltage controlled by manually configuring a physical tap. The RMU captures readings at a set frequency, anywhere from hourly to once weekly and uploads the readings to a secure database. Additionally, the RMU is set up to report exceptions immediately, resulting in an alert passed to the pipeline operator. An RMU can take multiple types of cathodic protection readings simultaneously, with the DC voltage and DC current being of interest in this study and shown in the diagram in Figure 1. Asset owners and operators can then view these readings and ensure their assets are sufficiently protected from corrosion.

In addition to CP relevant readings, other metadata is also captured, including the GPS location, ambient temperature and whether the RMU is performing a synchronized interruption of the rectifier.

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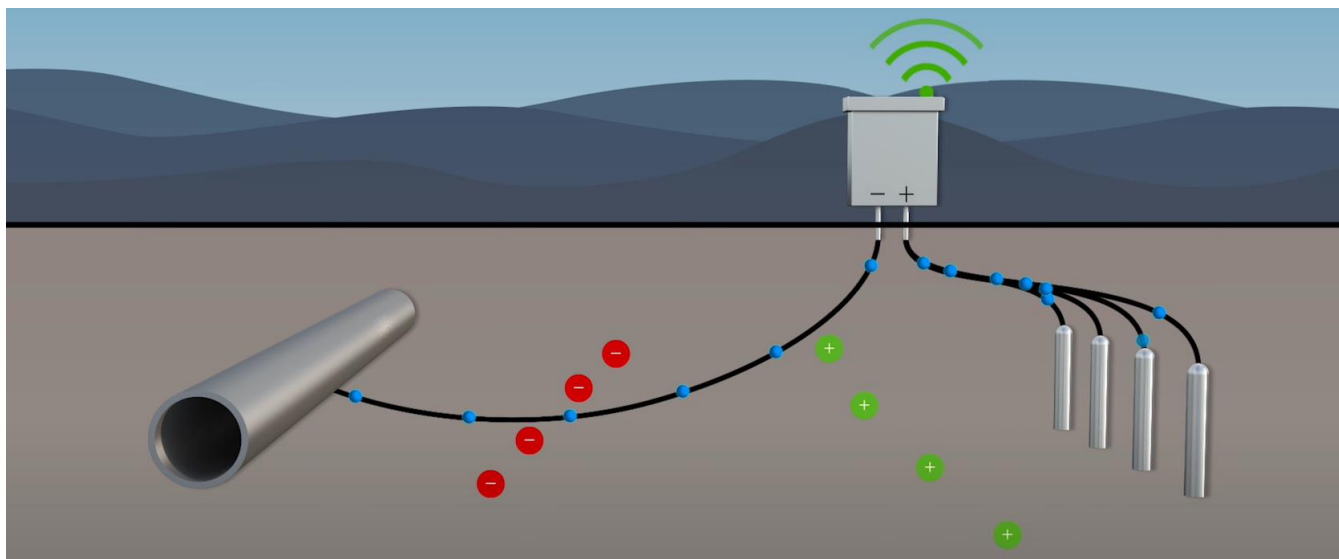


Figure 1: A typical rectifier RMU setup. The rectifier (top) is physically connected to the pipeline (bottom left) and the anodes (bottom right) by cabling. The circuit is completed by the soil. The electric current counteracts the electrochemical process of corrosion.

To obtain a more complete picture of the Impressed Current Cathodic Protection (ICCP) rectifier system, a calculation of system resistance is made. Following Ohm's law, resistance is obtained by taking the voltage and dividing it by the current. System resistance is independent of tap changes on the rectifier. This hides the changes associated with tap changes and highlights physical changes to the system, which operators may find to be more relevant. Depending on seasonal factors and the physical setup of the rectifier-anode-pipeline system, the resistance may fluctuate cyclically with a one-year period. Soil resistance is influenced by moisture, temperature, presence of ions and soil type. Previous studies have demonstrated that seasonal moisture and temperature changes are the two biggest factors driving cyclical soil resistance⁷⁻¹⁰. Figure 2 provides an example of the voltage, current and calculated resistance for an RMU on a rectifier.

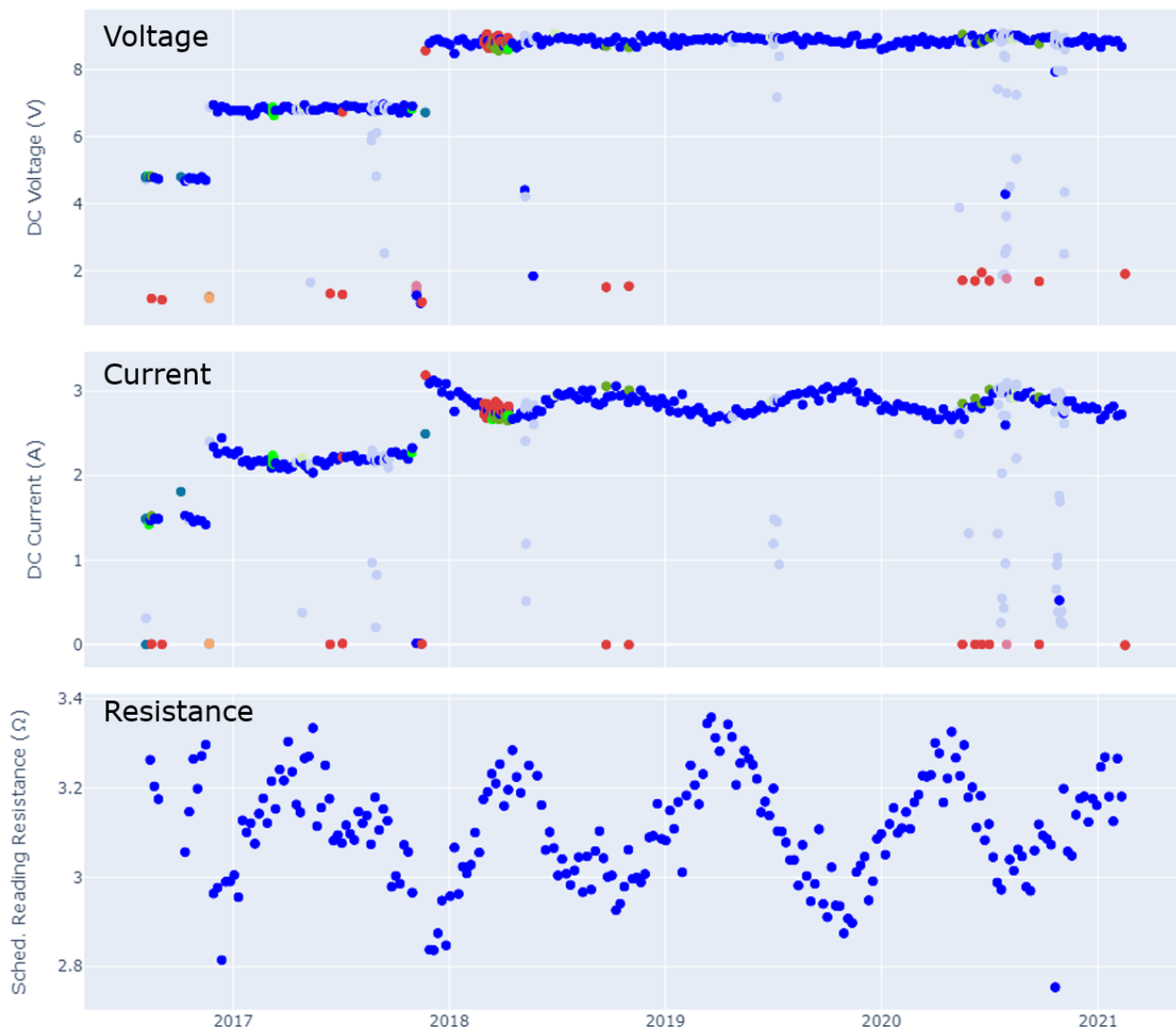


Figure 2: Historic reading for an ICCP rectifier. Voltage (top), current (middle) and resistance (bottom) are shown for a four-year period. Blue markers indicate scheduled readings, while other colours indicate readings due to interruption, planned outages or exceptions. The resistance is calculated using only scheduled readings, for a cleaner dataset.

Previously published data from sites across the United States shows that the annual/seasonal behaviour of ICCP system resistance can be predicted using soil moisture and soil temperature profiles of the rectifier location¹¹. Equation 1 describes the sinusoidal trend of system resistance, with A representing resistance variation's amplitude, t representing the normalized calendar date (which will fall between 0 = January 1st and 1 = December 31st), ϕ representing the phase-offset or physically the calendar date where maximum resistance is observed, and y_o representing the nominal average resistance.

$$y = A \cos(2\pi t - \phi) + y_o \quad [1]$$

For a significant number of rectifiers, Equation 1 is not sufficient to describe the long-term observed behaviour of system resistance. The average resistance may increase or decrease over time and can be attributed to factors including groundbed depletion, groundbed drying or pipe coating deterioration.

Resistance Trends

A repository of historic rectifier readings allows for long term trends to be tracked over time. Dynamic thresholds can be set to alert on statistically significant trends. In an example scenario shown in Figure 3, the mean (μ) and standard deviation (σ) are calculated over the course of the first year of readings. A threshold of twice the standard deviation above and below the mean is displayed in red. A second calculation of the most recent year's mean is performed, and a check is made to determine if this value is above or below the threshold. This is shown in Equation 2.

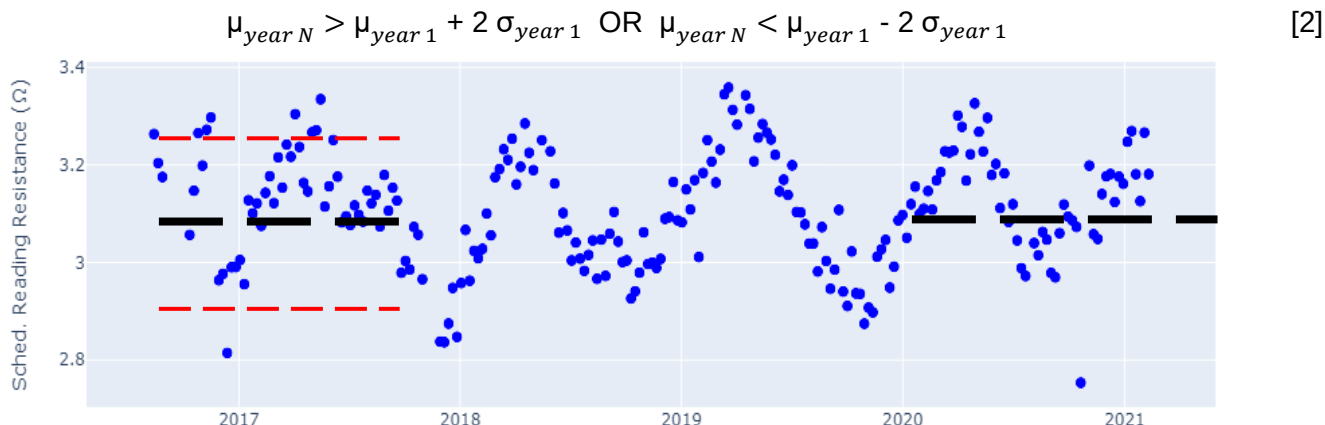


Figure 3: Resistance over a four-year period. Mean resistance measurements calculated in the first and last year of data are displayed with a dashed black line. Red dashed lines indicate an upper and lower bound defined by the mean $\pm$ 2 standard deviations.

In this way, long term (multi-year) reading trends for each RMU were determined.

A steady long term resistance trend is desirable from a cathodic protection perspective as this indicates the rectifier-anode-pipe electrical profile is stable. There are, however, a significant number of sites with a long-term resistance trend increasing or decreasing. Many factors on site influence the resistance, including anode degradation, drying of the groundbed, formation and growth of holidays in the pipe coating and environmental changes. Depending on when and how these changes manifest, the resistance may gradually or suddenly change over time. The goal of this project is not to classify which factors were influencing each rectifier, rather to take all factors in aggregate and develop a process to predict resistance trends.

The resistance trends were classified without knowledge of maintenance events which took place on site. Maintenance events which affect the resistance could be considered in future iterations of the prediction model but were not presently used as this information was not readily available.

Location and CP Relevant Meta-Data

Eight hundred forty-eight RMUs associated with rectifier setups across Canada were considered for this study. To see long term trends, at least two years' worth of readings were necessary, with a maximum of ten years. Although the RMU takes additional readings during interruptions and when exceptions are captured, only scheduled readings were considered to assure clean datasets.

Using the method described above, the RMU reading trends were calculated and RMUs were separated into steady, increasing and decreasing long-term resistance. An example plot of each type is shown in Figure 4.

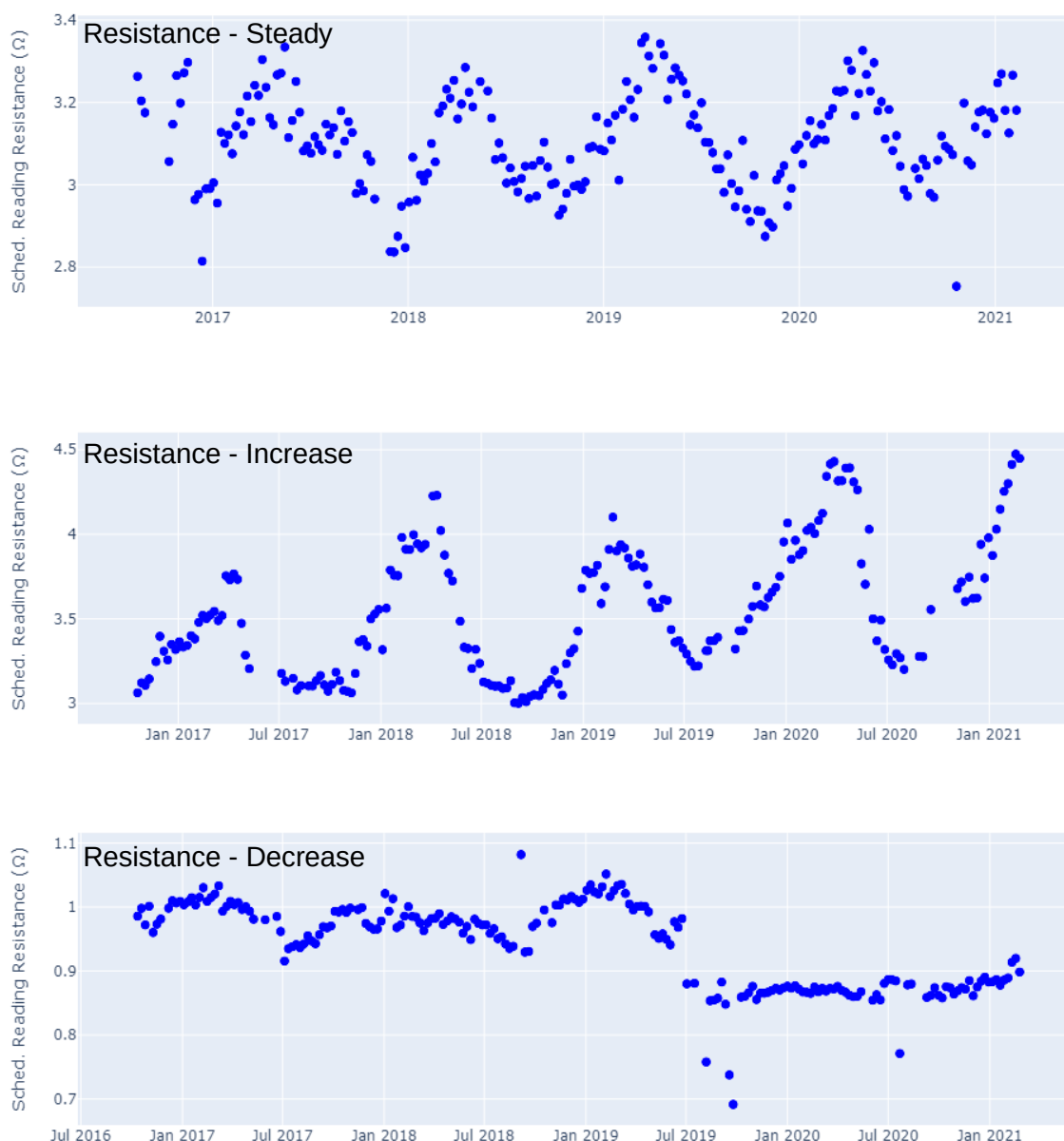


Figure 4: Example historic reading plots for three different RMU locations. These locations are displayed as examples of the three long-term trends. Steady (top), increasing (middle) and decreasing (bottom) are displayed.