1. What is the innovation?

With increasing scenarios of high voltage alternating current (AC) power lines being co-located with pipelines in a shared right-of-way, the importance of obtaining high quality information on the AC power flow of the nearby power lines is critical to appropriately design mitigation for, and monitor for the effects of AC corrosion. The AC voltage induced onto the pipeline creates a potential difference between the pipeline and the surrounding soil. This potential difference creates elevated risk for accelerated AC corrosion of the pipeline wall, especially in locations where insulating coatings have failed (holidays). It is often a challenging process to obtain this AC power flow data from the power line companies, and if obtained, often does not communicate the dynamic load flow patterns of power lines as they typically vary minute to minute and seasonally. Multiple factors contribute to the threat severity of AC corrosion including the separation distance from the pipeline to the AC source, the soil resistivity, co-location length, crossing angle, phasing arrangement, and the power line current which can be easily obtained. However, without insight into the actual power line current, assumptions must be made creating uncertainty in the confidence of an AC mitigation system design.

LineVision's innovation is a new field sensor platform that collects and disseminates real time data on the AC power flows and conductor phase arrangement independent of the involvement of the power line companies. The patented technology called LineVision PACT™, utilizes magnetic and electric field sensors to collect measurements of the Electromagnetic Field (EMF) that the power lines generate when AC power is flowing on them. The collected measurements are remotely communicated to servers where the data is processed through proprietary algorithms and the AC current flowing on the power line is able to be determined.

2. How does the innovation work?

Until now, pipeline operators have essentially been forced into making a "best guess" when dealing with AC current flows and resulting interference and corrosion. LineVison's technology takes the blindfold off for corrosion engineers and allows for real time power flow data collection. How we do it: When AC current flows along an electric transmission line in North America, a 60 Hz AC magnetic field (B-field) is produced, and this current on the power line can vary greatly based upon the demand for power or nearby levels of generation.. In other parts of the world, such as Europe, a 50Hz electric system is used but the same physics apply and the equivalent measurements can be made. The voltage on the power is usually constant as the electrical equipment is designed to a specific voltage level. The voltage of the power line produces an electric field (E-field).

LineVision's remote monitoring system is ground-level based, with no equipment contacting the pipeline or power line and typically installed in the shared right-of-way where pipeline owner easements exist. These Electromagnetic Field (E-Fields and B-Fields) values are measured by the sensors, then securely and wirelessly transmitted to servers where analytical computations take place. With the known geometry of the installed sensor relative to the powerline, applied physics can be used to determine the amount of current (amps) flowing on the power line.

The fundamental equation utilized to determine the current flowing on a transmission line is the Biot-Savart law (Equation 1), which describes the magnetic field generated by an AC current.

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int_C \frac{I d\mathbf{l} \times \mathbf{r}'}{|\mathbf{r}'|^3}$$

B(**r**) = Vector magnetic field at position **r**
μ_0 = Permittivity of free space
I = Electric current
r' = Radial distance from conductor
*d***l** = Conductor element

Equation 1: Biot-Savart Law

This sensing method allows for the determination of relevant line characteristics, as the amplitude of the magnetic field can be related to the amount of current on the line provided that the distance from the remote monitoring system to the power line is known.

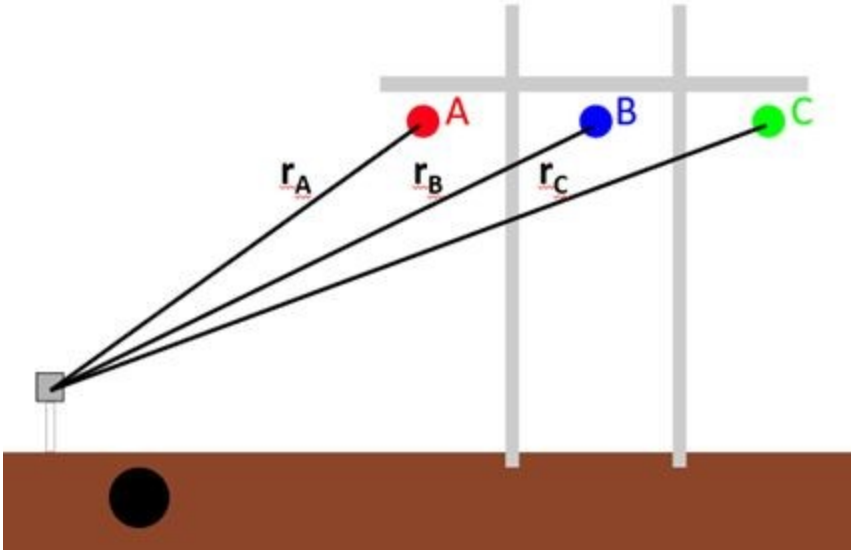

Figure 2: Illustration (not to scale) showing the relative distance required to be known from the monitor to each of the three phases.

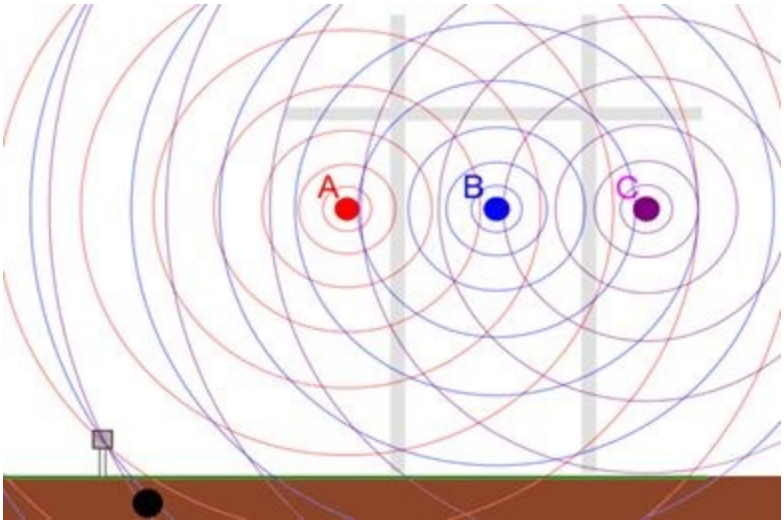

Figure 3: Illustration (not to scale) showing the EMF emitted from each of the three phases.

Monitoring systems are installed by securing the weatherproof sensor enclosure onto a mounting post or other rigid structure. Mounting posts can be permanently secured on a concrete foundation approximately 18” deep, or positioned by other methods for semi-permanent monitoring that can be relocated. The monitors are self-powered with a battery that is continuously recharged with a small solar panel. Once installed, field crews use laser measurement tools to record the distances from the device to each of the phases on the monitored circuit as shown in Figure 2. Cellular or satellite modems are then configured for data transfer and results are displayed on a secure web data-portal.

Figure 4: LineVision PACT monitor installed in the field.

3. Describe the corrosion problem or technological gap that sparked the development of the innovation. How does the innovation improve upon existing methods/technologies to address this corrosion problem or provide a new solution to bridge the technology gap?

The LineVision technology platform continuously collects and disseminates real time data on the AC power flows and conductor phase arrangement whereas previously, pipeline operators had to request data from power utilities which took months, was costly, often incomplete, did not communicate the dynamic nature of power flows over hours/days/seasons, and did was not updated as macro grid power flows evolve.. Until now, pipeline operators have essentially been forced into making a "best guess" with the limited AC current flows information they had available. LineVison's PACT technology provides corrosion engineers with the data they need to improve models for optimized and right-sized AC mitigation system designs and to monitor the source of the AC threat on a continuous basis with alerts as power flow levels change over time.
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EMF sensors compliment existing monitoring practices conducted by pipeline operators; the technology does not serve as a replacement for other RMUs. LineVision correlates monitoring with coupon-based corrosion monitors, soil resistivity monitors and improves the accuracy of pipeline network health condition software systems with real-time AC data.

4. Has the innovation been tested in the laboratory or in the field? If so, please describe any tests or field demonstrations and the results that support the capability and feasibility of the innovation.

Yes, multiple blind comparisons have been performed analyzing the current flows as reported by the LineVision PACT system to granular time-series data obtained directly from power utilities. The following example in Figure 5 shows one such double blind comparison on a 138kV transmission line in Indiana, United States, as measured by the LineVision system and as compared to the utility's Supervisory Control And Data Acquisition (SCADA). The field-based sensor measurement exhibited a strong correlation to the utility SCADA. Specifically the results obtained were a RMS Error of 9.65 Amps, an Average Percentage Error of -0.42% and an Absolute Percentage Error of 1.22%.

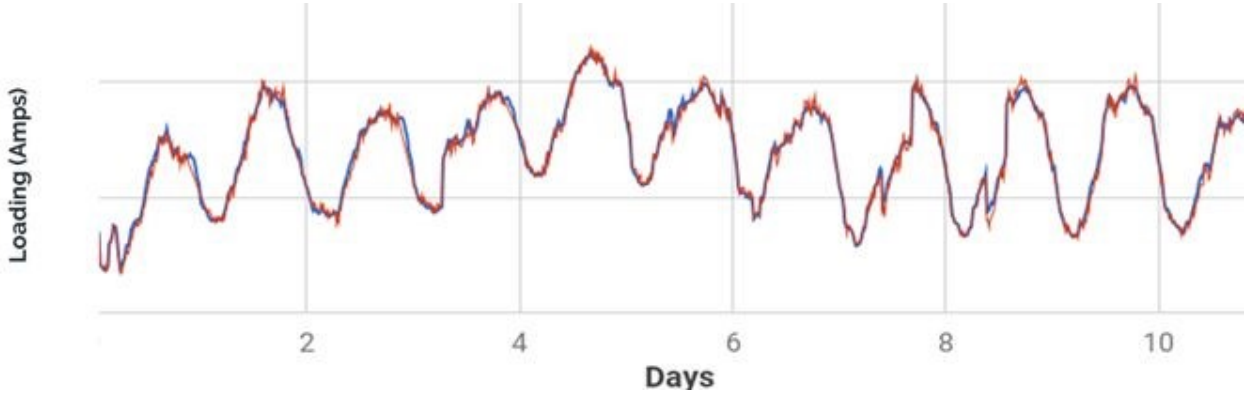

Figure 5: Blind comparison of sensor data compared to utility SCADA. Utility SCADA data is displayed in red and sensor data is displayed in blue.

5. How can the innovation be incorporated into existing corrosion prevention and control activities and how does it benefit the industry/industries it serves (i.e., does it provide a cost and/or time savings; improve an inspection, testing, or data collection process; help to extend the service life of assets or corrosion-control systems, etc.)?

The data provided by LineVision PACT takes the place of the best-guess assumptions about high voltage AC power line loading levels or the limited information provided by electric power utilities when performing AC Interference Studies. By deploying the sensors, the data can be collected faster than making requests to utilities which can take months and is often very expensive. Furthermore, the data provided by the sensors is a complete picture of the dynamic nature of power flows capturing information that can be used to right-size mitigation systems so they aren't under-sized, putting pipelines at corrosion risk; or over-sized, spending excessive funds on unnecessary mitigation. Additionally, the sensors provide ongoing monitoring of the overhead lines so pipeline operators can receive alerts if the power flow on a nearby line changes and is now posing an increased risk of AC interference to the pipeline. Furthermore, the data collected by the LineVision system can be used to inform other RMUs when it is the "right" time to take a sample of current density or corrosion rate such that it corresponds to the peak loading observed on the power line.

6. Is the innovation commercially available? If yes, how long has it been utilized? If not, what is the next step in making the innovation commercially available? What are the challenges, if any, that may affect further development or use of this innovation and how could they be overcome?

Yes. After proving the technology with a trust major midstream pipeline customer in a pilot project, the technology is now commercially available and has been for approximately one year, with deployments having doubled in size in 6 months and the footprint of installed LineVision units expanding to Oklahoma, Texas, North Dakota and Kansas.

7. Are there any patents related to this work? If yes, please provide the patent title, number, and inventor

Method and system for autonomous measurement of transmission line EMF for pipeline cathodic protection systems

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