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Implications of Solar Facilities on Adjacent Pipeline Infrastructure

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As oil and gas operators ramp up their efforts to reduce their carbon footprint, more renewable energy projects will be constructed adjacent to pipeline infrastructure. As part of this effort, a major North American pipeline operator has initiated a program to install solar facilities at its pump and compressor stations[1].

These solar facilities often involve the installation of thousands of interconnected and grounded bare steel piles, which could compromise the corrosion protection of nearby pipeline assets. While potentially also introducing alternating current (AC) and direct current (DC) interference risks on buried pipelines, the solar facilities themselves could be subjected to interference from the pipelines' cathodic protection systems. This article discusses a pilot project where several key design factors were considered for minimizing interference and corrosion risks to both pipelines and solar facilities coexisting in the same corridor.

Solar System Operation Background

Figure 1 shows a simplified diagram of a solar photovoltaic (PV) system.[2] The solar modules, interconnected in strings, generate DC power. Multiple strings are routed into a combiner box, which combines the DC inputs into a single DC output. The output is fed into the inverters, which convert the DC to three-phase AC power. The AC is then stepped up at the transformers (typically to 34.5 kV), and directed through an AC switchgear (with circuit breakers for fault protection) into a sectionalizing cabinet, where the solar feeder cables are interconnected to feeders from the substation.

The two main types of PV system grounding that are typically utilized are shown in Figure 2.[3] In the floating DC system, neither the positive nor the negative is grounded. In the negative DC system grounding configuration, the DC negative is grounded at one point, typically at the inverter.

If a short were to occur on a single point negative ground system shown in Figure 3 (on the left)[3], current would flow through the soil to the ground point at the inverter in a parallel path to the negative cable. If the DC fault currents are sufficiently high, they would be detected and interrupted by the ground-fault detector interrupter (GFDI).

To generate any significant DC ground currents on a DC floating system, two simultaneous shorts would need to occur, as shown in Figure 3 (on the right).[3] Ground fault monitoring for floating systems is achieved by monitoring the DC insulation resistance of the PV input (array) via insulation monitoring devices (IMDs). On an isolated system, although the IMD may detect a fault, it would not necessarily interrupt the fault and prevent operation of the inverter.

Based on several sources[3-8], DC ground currents during normal operation are expected to be in the microamp to milliamp range, and for undetected or "blind spot" faults, in the tens to hundreds of milliamp range—neither of which would pose a significant risk to adjacent pipelines.

However, to maintain operability, common practice by solar plant operators is to set the current leakage detection limits higher to avoid nuisance trips. This can result in the continued operation of inverters with significant ground faults and potentially result in DC interference risks to pipeline infrastructure.

Pilot Project Approach

A pilot project involving the design of three solar PV sites to be installed at existing pump stations was initiated. The pipeline corrosion prevention team was engaged early in the design process to review the conceptual design and determine the potential cathodic protection (CP) implications to the pipeline infrastructure and facilities.

A review of the design of the solar sites indicated that they would be directly connected to the existing substation inside each of the pump stations and, as such, their grounding systems would be interconnected in accordance with electrical codes. As this pipeline operator does not isolate their mainlines from their stations and facilities, and the grounding systems of the substation and pump station are interconnected, this would have effectively connected the solar grounding system (including the piles) to the pipelines. It was anticipated that the bare steel piles would drain a substantial amount of CP current intended for the pipelines, if left interconnected. A summary of the three solar sites is provided in Table 1, along with the anticipated CP current drain to the piles.

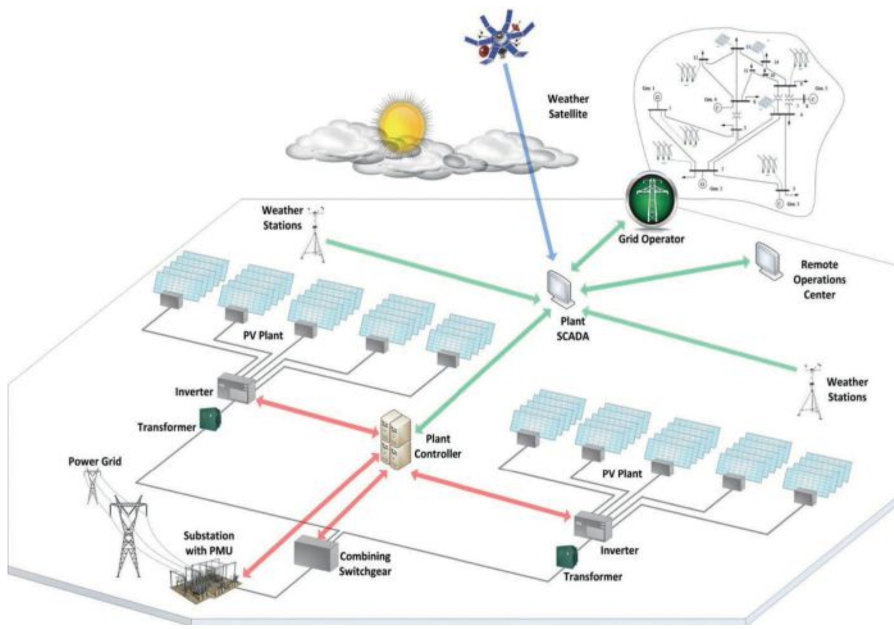

FIGURE 1 **Solar PV generating station components.**

To ensure that the CP of the existing pipeline infrastructure was not adversely affected, the solar grounding system design was modified to be fully isolated from the substation in DC. However, AC continuity between the two grounding systems was required to ensure safety under AC fault conditions, both inside the solar facilities and the pump stations. This was achieved by installing an appropriately sized DC decoupler between the two grounding systems at the sectionalizing cabinet, which is where the 34.5 kV solar AC feeders connect to the AC feeders from the substation.

Non-metallic fence sections were installed to isolate the fences at interconnections between the existing pump station fencing and the grounded solar PV facility fencing. The isolation was verified to avoid any bypass via interconnected station fencing, monitoring cables, or other equipment.

An alternative approach to isolation that was considered involved the installation of additional CP systems to cover the CP current losses to the solar infrastructure. However, it was determined that this would be a more costly and complex solution and

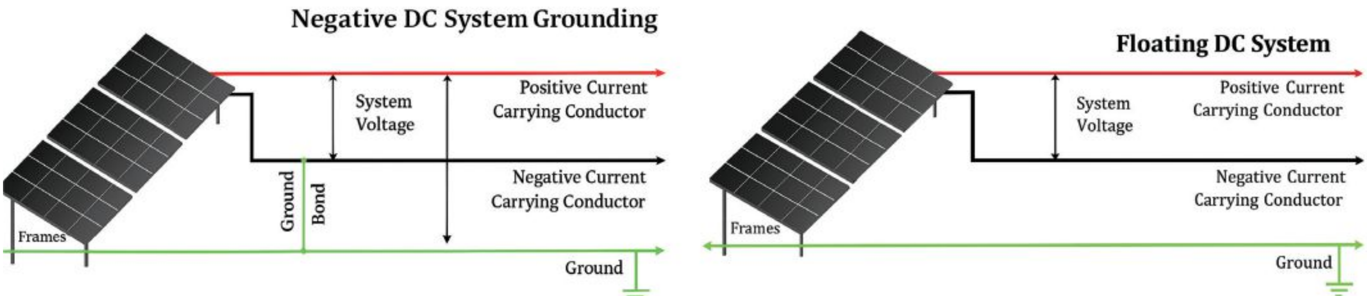

FIGURE 2 **Types of solar PV system grounding.**

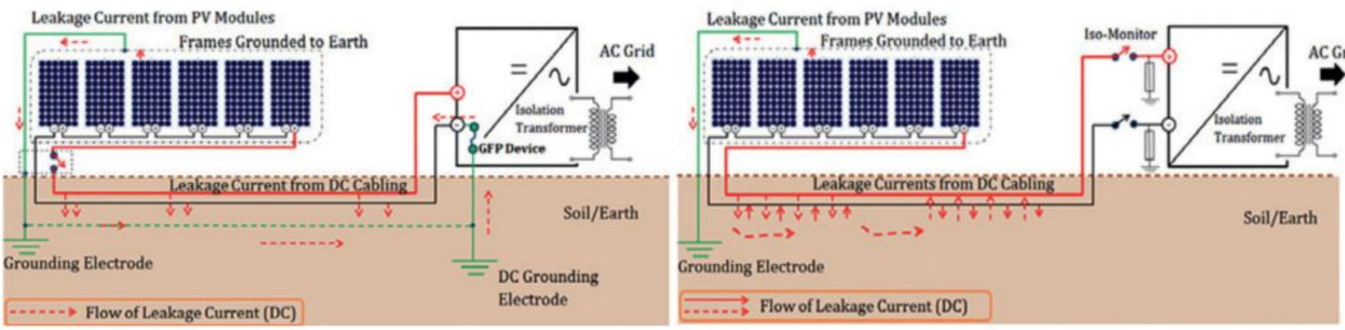

FIGURE 3 Solar PV DC fault current paths.

therefore would typically only be viable for smaller solar farms. In addition, CP shielding or current redistribution due to the proximity of the bare solar piles to the pipelines could pose a potential risk.

DC Interference Risk to Solar Infrastructure

As the pump stations at all three pilot project sites have existing impressed current CP systems in proximity to the solar arrays, a significant risk of DC interference on the solar piles that are adjacent to the pipeline corridor can be expected.

Figure 4 shows the initial layout for the Site 1 solar facility. When overlaying the solar arrays with the CP systems and pipeline infrastructure, a conflict with the existing CP anode bed was detected. As this was detected early in the design phase, the solar arrays could be reconfigured to resolve the conflict. However, due to land restrictions, the solar arrays could not be moved to a remote location completely outside of the CP anode gradient. As such, the piles in proximity to the anode bed will pick up CP current, which will then be discharged back to the mainline pipelines to return to the negative terminal of the rectifier, completing the circuit. Due to a risk of corrosion at the discharge locations, DC interference testing should be performed to determine whether mitigation would be required.

DC Interference Risk to Pipelines

Because the solar PV facilities in these pilot studies consisted of fully floating DC systems with IMDs, the DC interference risk was expected to be minimal. Any single point DC to ground shorts/faults, on either the negative or positive, are not expected to result in any significant earth currents. Furthermore, loss of DC isolation due to a short would be detected by the IMDs and result in an alarm.

AC Interference Risk to Pipelines

The 34.5 kV feeder cables to the substation and interconnections between the solar sites are typically via overhead cable when crossing the pipeline corridor. For this project, the power feeder cables for all underground crossings of the pipelines were installed inside non-metallic conduit extending a minimum of 3 m (10 ft) on each side of the crossing to mitigate any potential arcing risks.

The final solar station grounding studies were reviewed for potential safety risks due to fault voltage transfer to the pipeline infrastructure related to an AC fault to ground at the solar facilities.

No significant AC interference risks were identified, as the generation tie-ins were via an existing substation and did not involve any new transmission powerlines. There were also no significant existing parallels between transmission powerlines and pipelines.

Monitoring Equipment

Additional test stations with corrosion rate probes (CR probes) and remote monitoring units (RMUs) were installed on the pipelines where they traverse through the solar farm, or are in proximity to the solar array piles and grounding system, to monitor CP levels and interference risks.

Commissioning

A commissioning procedure, to be per-

TABLE 1 SUMMARY OF PILOT SOLAR SITES

Solar Site	DC Output (MW)	AC Output (MW)	Number of Piles	Surface Area of Piles	Estimated CP Current Drain to Solar Piles
Site 1	15.21	12.15	4729	6,620 m^2 (71,257 ft^2)	99 A
Site 2	10.59	8.55	3259	4,562 m^2 (49,104 ft^2)	68 A
Site 3	13.24	10.13	4134	5,788 m^2 (62,392 ft^2)	87 A

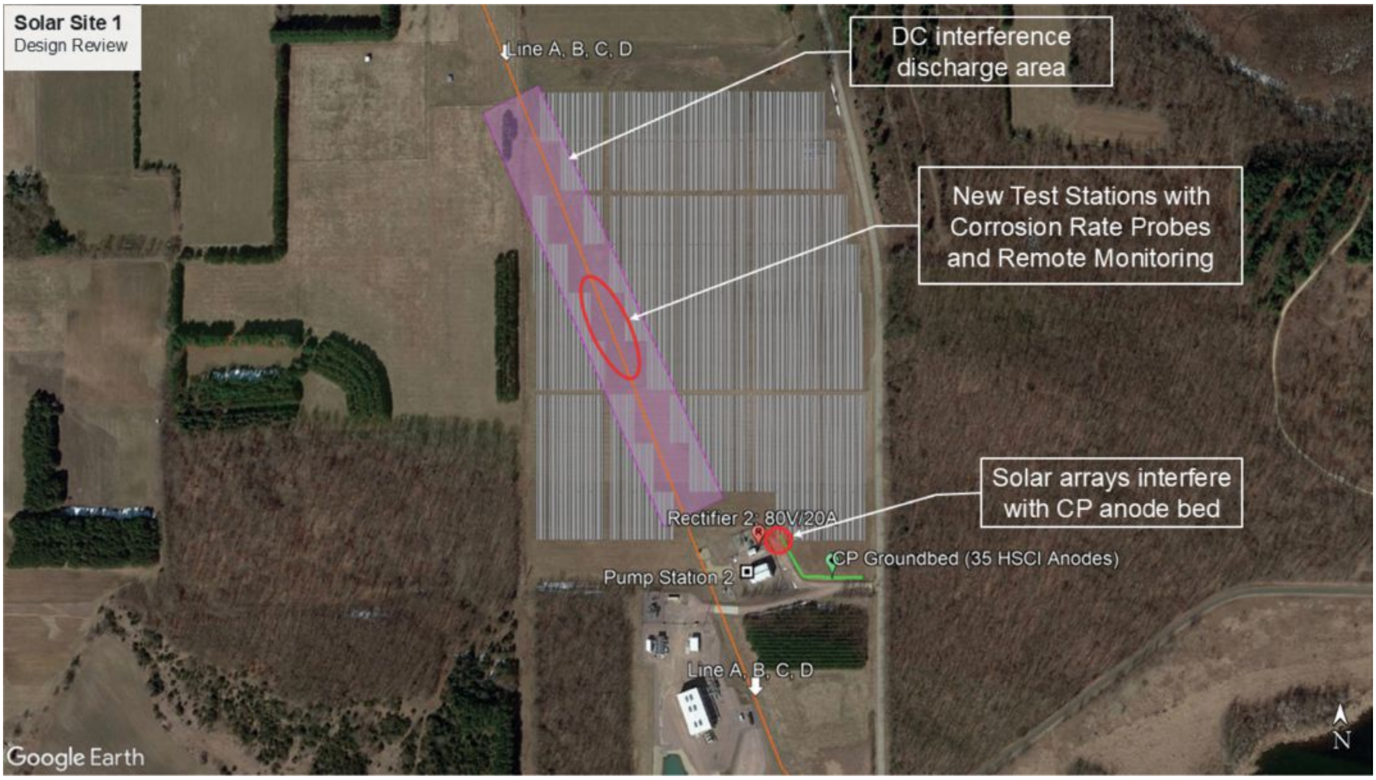

FIGURE 4 Solar PV site 1 layout (Source: Google Earth 2022).

formed after energization of the solar facilities, was prepared for the pilot sites. The purpose of the testing would be to ensure that the DC decouplers are operating effectively, that the two grounding systems are fully isolated in DC, and that the performance of the CP system has not been adversely impacted:[9]

- Test the operation of the DC decoupler and for isolation between facilities.
- Perform a CP test post-survey and compare to baseline data.
- Perform a close-interval survey (CIS) on the pipelines through the solar facility and compare to baseline CIS (if performed).
- Data log AC and DC potentials for a minimum 24-h period on test stations in the area.
- Perform DC interference testing on the solar array piles.

Pipeline Cathodic Protection Performance Considerations

Based on this pilot study, it was learned that CP impact assessments should be performed during the pre-design phase of any solar projects to determine the project-specific CP-related risks and requirements. Such assessments should include:

- Reviewing the solar PV system schematic, layouts, and details.
- Determining DC grounding system type, locations, and details on ground fault detection and interruption systems.
- Assessing the risk of DC interference to the pipelines due to uninterrupted ground currents during solar DC fault conditions.
- Reviewing existing CP anode bed, bond, and monitoring locations, and current CP protection levels.
- Calculating CP current drain (loss) to the piles and assess CP system requirements, if solar and pipeline grounding systems are to be interconnected.
- Determining the best course of action to mitigate the risks to the CP system (DC isolation is the recommended approach).
- Assessing locations with existing monitoring facilities along with requirements for addition of new test stations.
- Determining locations of CP anode beds and potential interference with the solar arrays.
- Reviewing solar grounding/fault study and assess pipeline safety and integrity risks due to transfer of fault voltages during an AC ground fault in the solar facility.
- Identifying powerline or AC feeder crossings with the pipelines and assess arcing risks.
- Assessing potential AC interference risks due to new or existing powerlines.

Solar Farm Design Considerations

Solar facility design factors that could be considered to minimize the CP and interference-related risks to the existing and new infrastructure include:

- Isolation of solar PV DC system (i.e., floating or single point grounded).
- GFDI and/or an insulation monitoring device (IMDs) to detect and inter-

rupt DC faults. DC faults resulting in current flow to the earth are to be quickly detected and interrupted. Operation in the faulted condition should not be permitted.

- A very low solar grounding resistance to minimize the transfer of unsafe fault potentials along the pipelines. Maintain a separation of 10 m (30 ft) from the pipelines to the solar arrays and related grounding equipment.
- Paralleling of powerlines with pipelines for long distances should be minimized or avoided (where possible).
- Solar arrays installed remotely from any CP anode beds.
- Isolating (non-metallic) fence sections between the solar fence at interconnections to the existing pipeline station fence to ensure isolation of the two grounding systems.
- Underground powerline cables crossing the pipelines installed in a non-metallic conduit extending a minimum of 3 m on each side of the crossing for distribution/collector power lines (<60 kV) and a minimum of 10 m for transmission powerlines (>60 kV).
- Reinforced concrete piles or non-metallic or coated piles should be considered to minimize CP current losses.

Conclusions

The installation of solar PV facilities adjacent to pipeline facilities can result in the following risks:

1. Loss of significant pipeline CP current to the solar piles and grounding, compromising the protection of the pipeline infrastructure.
2. DC interference on the pipeline due to undetected or uninterrupted earth currents resulting from DC faults on the solar arrays.
3. Transfer of hazardous fault voltages to the pipeline and facility due to an AC ground fault at the solar facility or associated equipment.
4. Risk of electrical arcing to the pipeline due to crossing underground powerlines or proximity to grounding systems.
5. AC interference due to new or upgraded existing paralleling powerlines.
6. Physical conflicts between the solar arrays and existing CP systems.
7. DC interference risks solar piles and grounding at the CP current discharge locations.

The paper[1] this article is based on present mitigation techniques to address the preceding risks. Those techniques include in-depth pre-design CP assessments, studies and modeling, proper isolation and grounding, design of monitoring equipment, system commissioning, and ongoing monitoring. Operator specifications should also be developed to ensure that CP requirements are consistently applied across all solar projects.

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