System Impact Assessment of a Proposed Geomagnetically-induced Current Field Test at a Dominion Energy Virginia Substation

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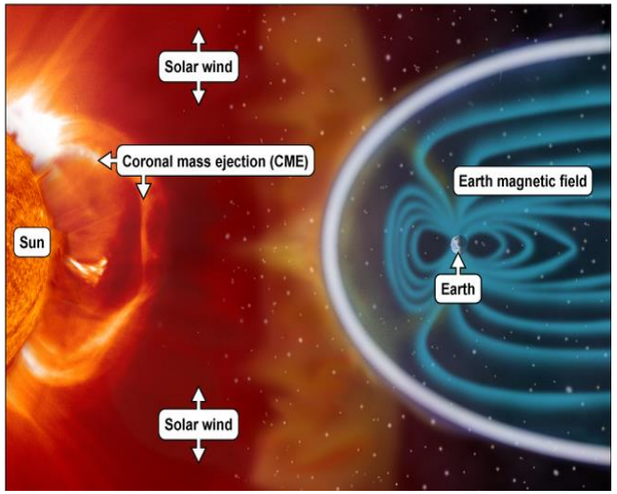
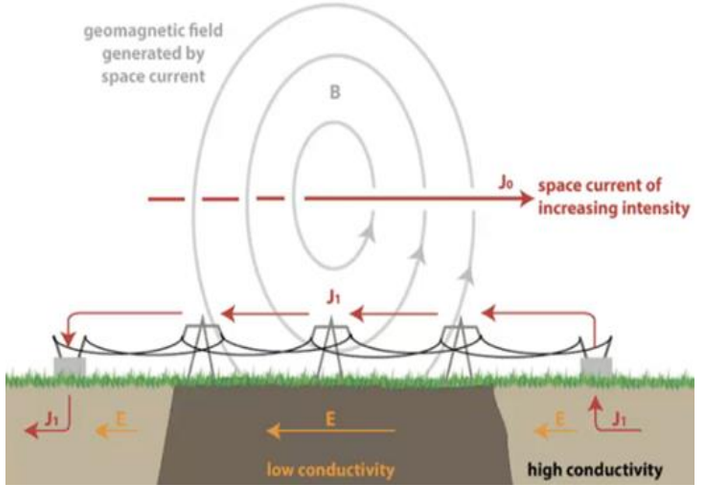
Background

- When coronal mass ejections are earth-directed, they can interact with the earth's magnetosphere and ionosphere to cause geomagnetic disturbances (GMD).
- GMDs amplify and perturb the magnetic fields and induce geoelectric fields on the earth surface which drives quasi-DC geomagnetically-induced current (GIC) to flow in electric transmission lines [3].
- These GICs can cause undesirable effects in the power system such as transformer overheating, tripping of capacitor banks, generator rotor heating, etc., which may culminate into blackouts.
- Well-known blackouts caused by GMD include the 1989 Hydro Quebec event and the 2003 Halloween event [4-8].



Source: [1]



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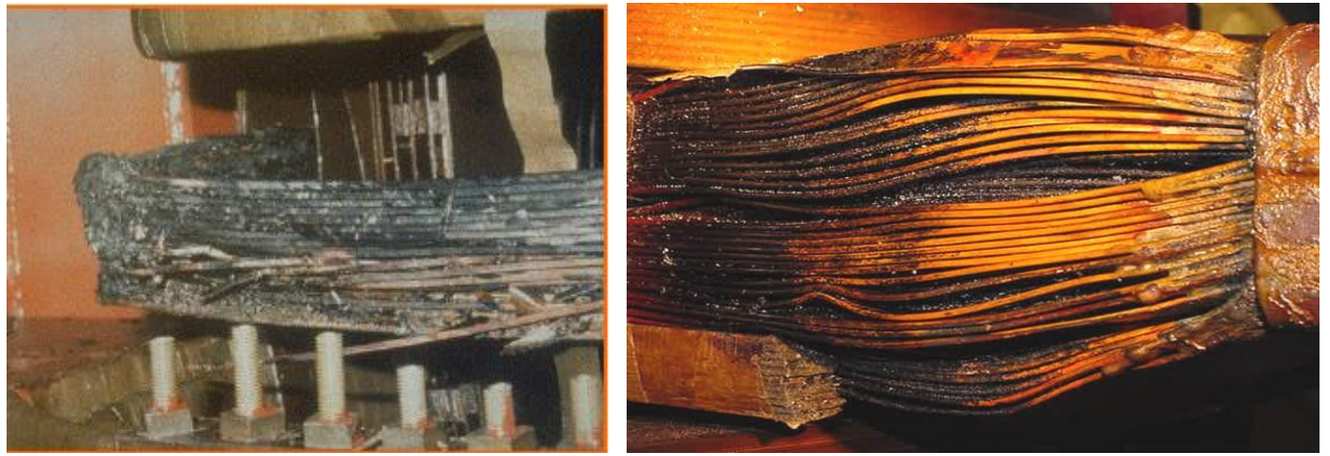

Evidences of transformer overheating due to GIC flow in 1989 at Salem Nuclear plant, NJ (left) and in 2003 at the Eskom station in South Africa (right). Source: [9]

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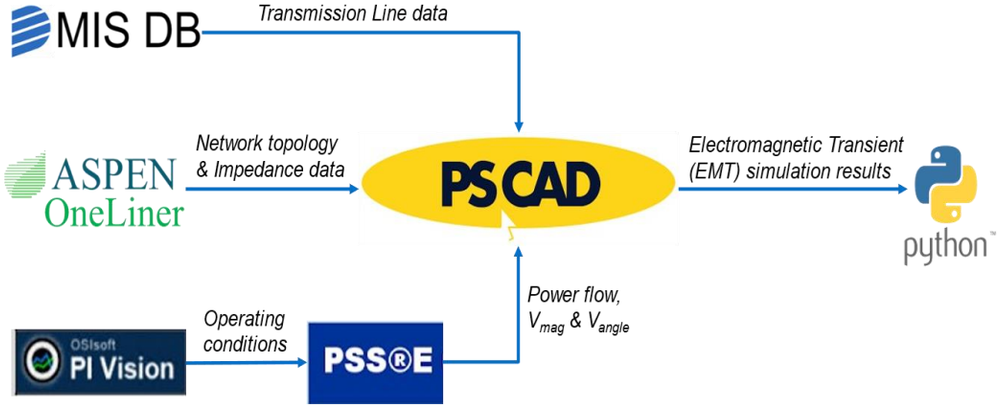
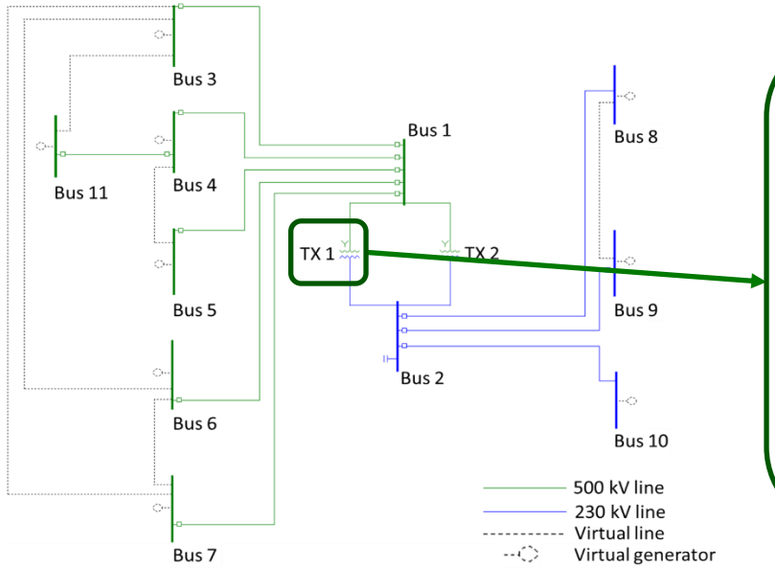
Research Objective & Methodology

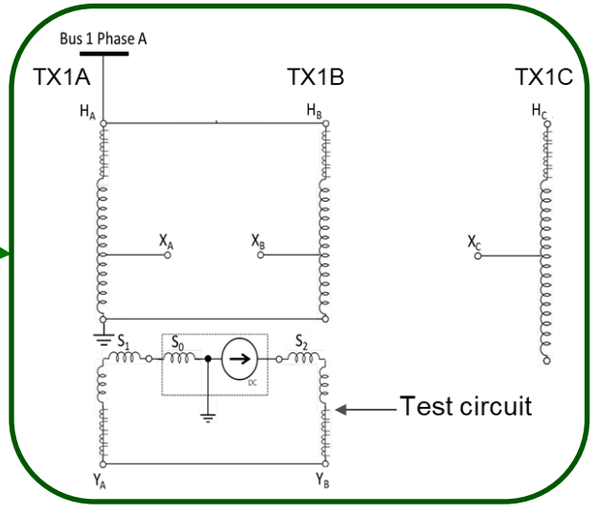
- Given that GMD effects on the electric grid can be severe and system-wide, there are numerous GMD/GIC related studies in literature and several simulation tools have been developed [10,11,12].
- However, only a few large-scale GIC field tests have been performed in the world to validate the accuracy of these simulation models [13, 14].
- The latest ones in the U.S. were performed in the 1980s, these may not be relevant today due to developments in transformer internal design.
- In response to this industry need, Dominion Energy performed a GIC field test at a 500/230 kV substation.
- The field test was performed on two 280 MVA, single-phase autotransformers.
- Before the field test, this research was conducted to investigate the potential impacts of the GIC field test on the Dominion grid.
- To perform the study, an 11-bus system was created as an equivalent of the DEV grid.



Overall Research Approach



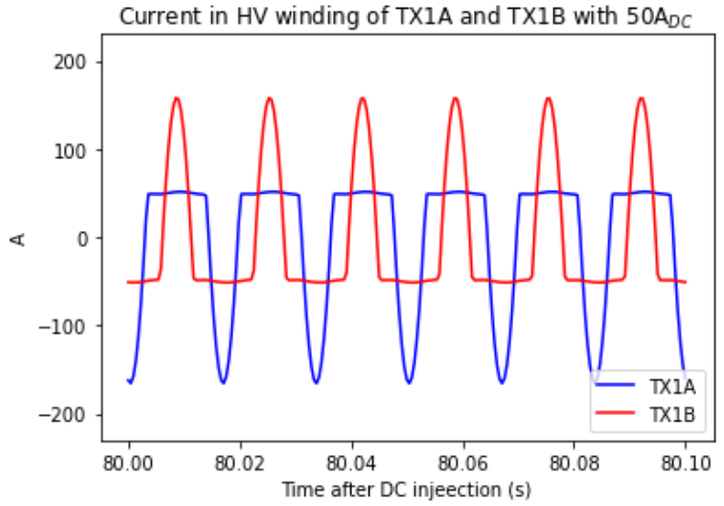
Reduced Model of the study area in Dominion grid



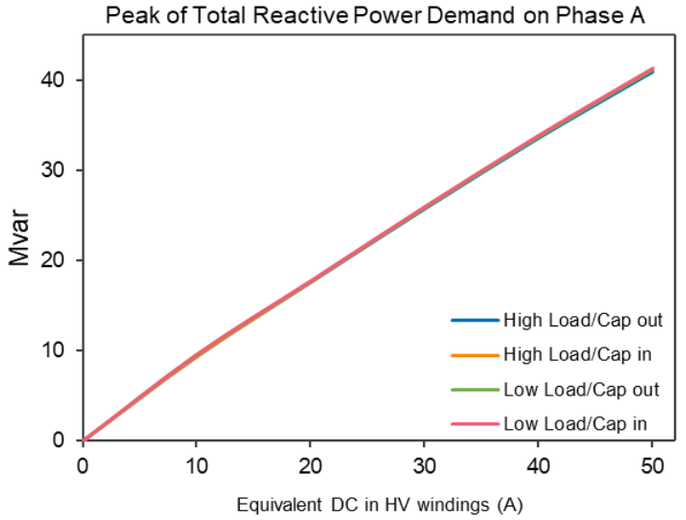
Modification of TX1 for the GIC field test

Results

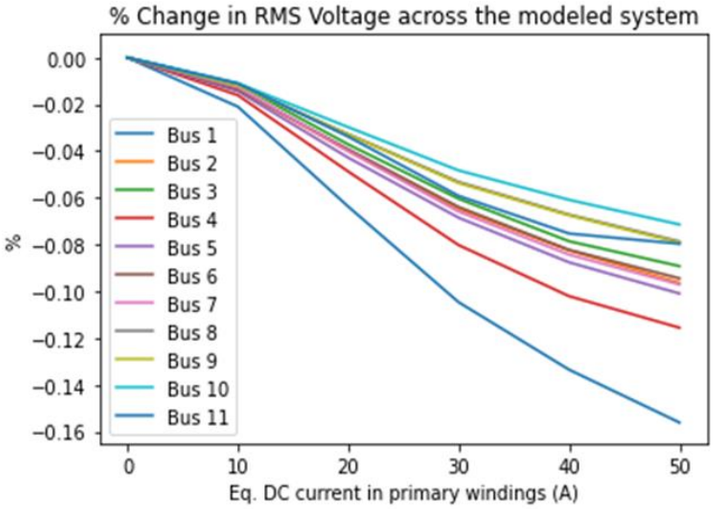
- On the primary side, current waveforms of both transformers have characteristic shapes indicating that the transformers saturated in opposite directions and at different half-cycles.
- The waveforms are dominated by the magnetizing current and DC current when saturated and unsaturated respectively as shown in Fig. (a).
- Fig. (b) shows the linear relationship between reactive power demand against injected DC magnitudes and that the relationship is linear and independent of operating scenarios.
- Maximum voltage drop was 0.16% as shown in Fig. (c)
- Reactive power demand on a single phase caused voltage unbalance of 0.4% which was lower than limits of 1% and 3% recommended in NEMA MG1[15] and ANSI C84.1[16] respectively.



(a)



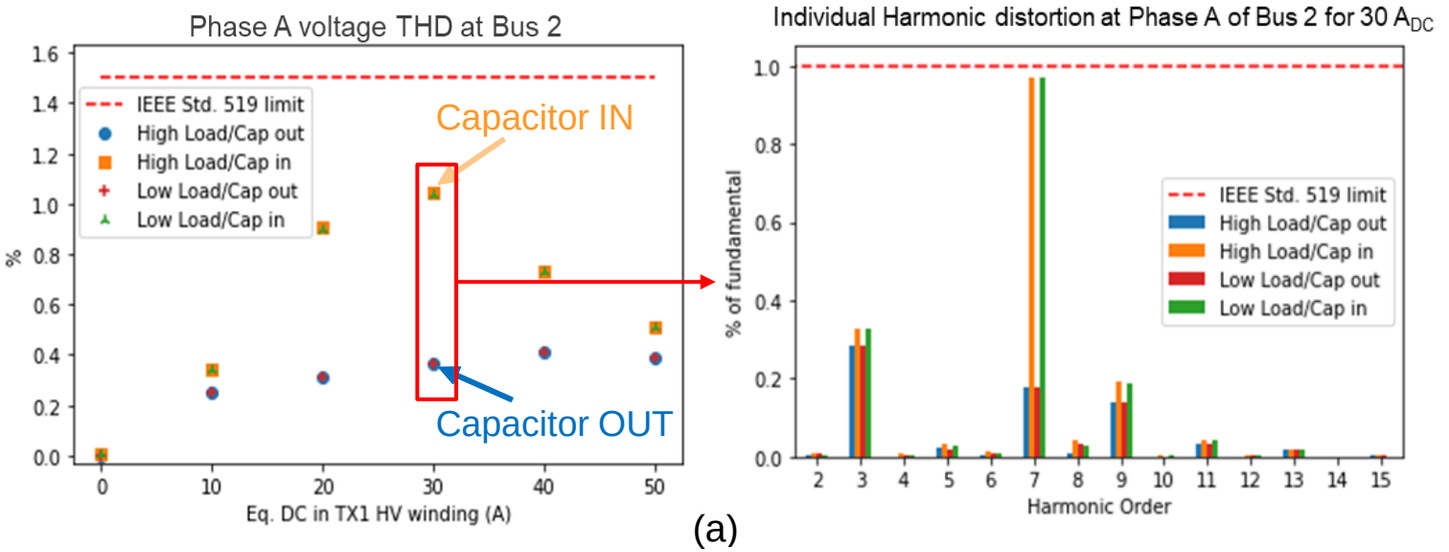
(b)



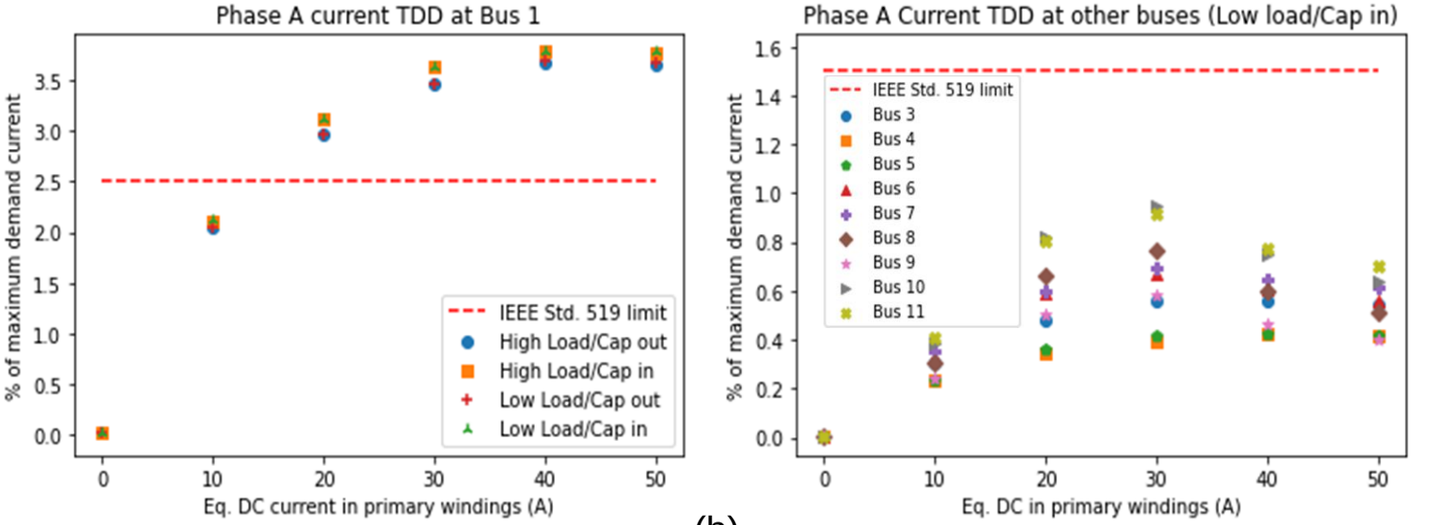
(c)

Results

- Voltage THD (*THDv*) was below IEEE 519 harmonic limits, however, capacitor operation significantly increased THDv (see Fig. (a))
- Frequency scanning showed that capacitor operation created potential for parallel response at the 7th harmonic.
- Thus, it was recommended to place the capacitor out of service during the GIC field test.
- Fig. (b) shows that Current Total Demand Distortion (*TDDi*) was above IEEE 519 harmonic limits for GIC equal or greater than 20 A/ph.
- This violation only occurred at Bus 1, *TDDi* at other buses upstream and downstream of Bus 1 were lower than the IEEE 519 limit.



(a)



(b)

Conclusion

- Other investigations performed in this study to prepare for the GIC field test involved:
  - Real and reactive power oscillations,
  - Sympathetic response of the parallel transformer,
  - Residual transformer magnetization between two DC injection periods
  - Current demand at transformer energization, and
  - Sensitivity analysis of simulation results to different EMT transformer models.
- Overall, the study indicated that the impact of the GIC field test on the Dominion grid will be minimal, and the continuity and quality of electricity supply will not be impacted.
- The results of this study gave Dominion Energy the *"green light"* to perform the GIC field test and it was successfully completed in the fall of 2022.
- There is ongoing work to compare the results of the simulation to the field measurements to validate the simulation models.

Acknowledgements

This work was primarily supported by Dominion Energy.

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