Assessment of Protection on Transmission Lines with Fixed Series Capacitors (FSC) using Hardware-in-the-Loop Testing

Abdulaziz Qwbaiban[1] , *Andrea Pinceti*, Ph.D.[2], *Katelynn A. Vance*, Ph.D.[2]

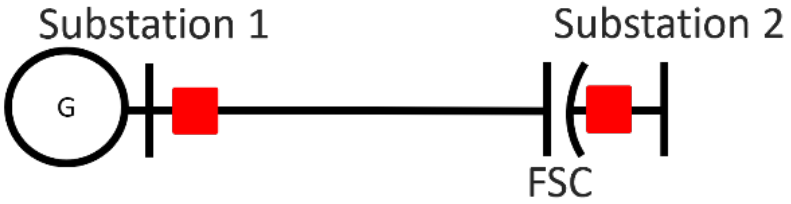
Georgia Institute of Technology[1], Atlanta, GA, USA

Dominion Energy[2], Richmond, VA, USA

Dominion Energy

Introduction

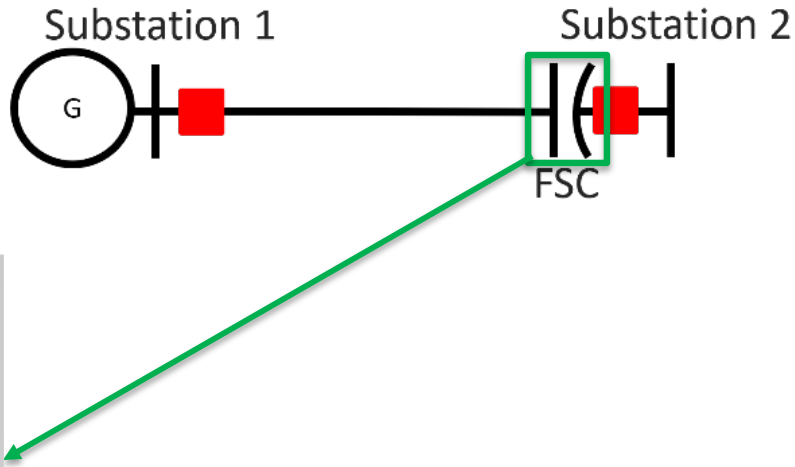
- Diverse and evolving generation portfolio
- 500 kV lines are critical for reliability
- Fixed Series Capacitors (FSC) are installed to improve power transfer capabilities and power system stability
- Protection challenges due to FSC
  - mis-operation of zone protection
  - interaction with FSC protection
  - effect on adjacent lines protection



Dominion Energy

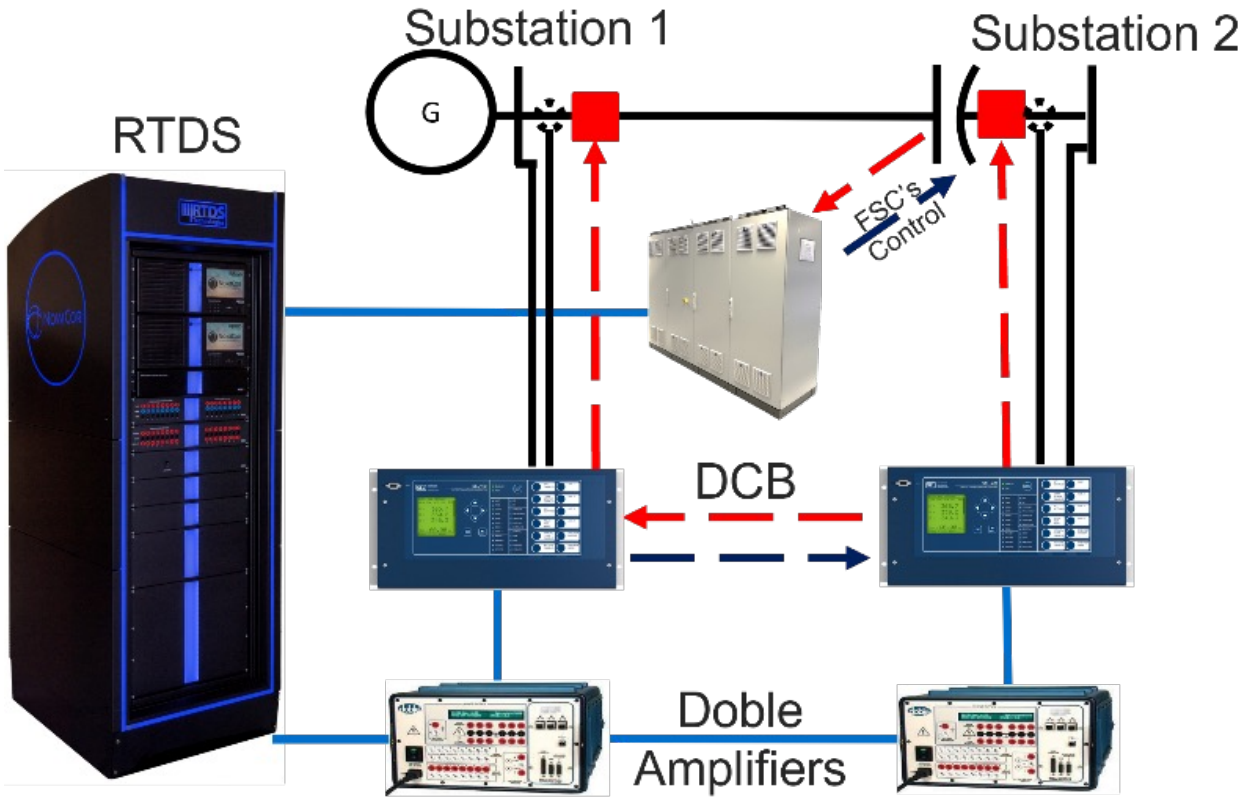
Introduction

- 3D Visualization of FSC connections



Dominion Energy

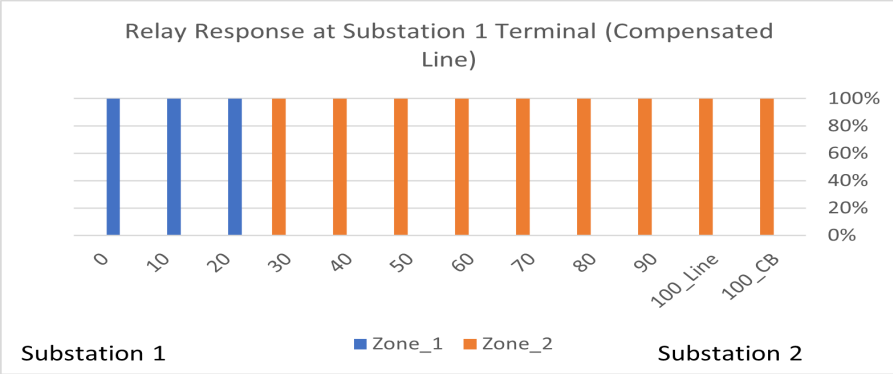
Hardware-in-the-Loop Testing

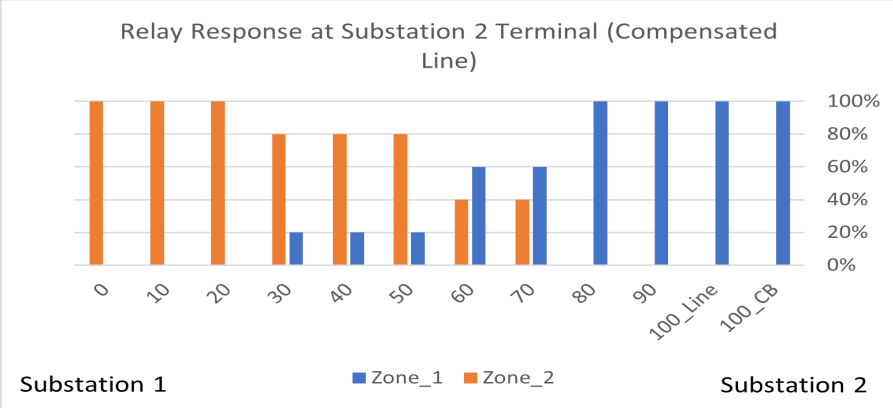


Dominion Energy

Simulation Results (FSC In-Service)

- For Substation 1, the underreaching Zone 1 element reached up to 20%
- For Substation 2, the underreaching Zone 1 element reached up to 70% with gaps
- Remaining parts were protected by the overreaching element Zone 2

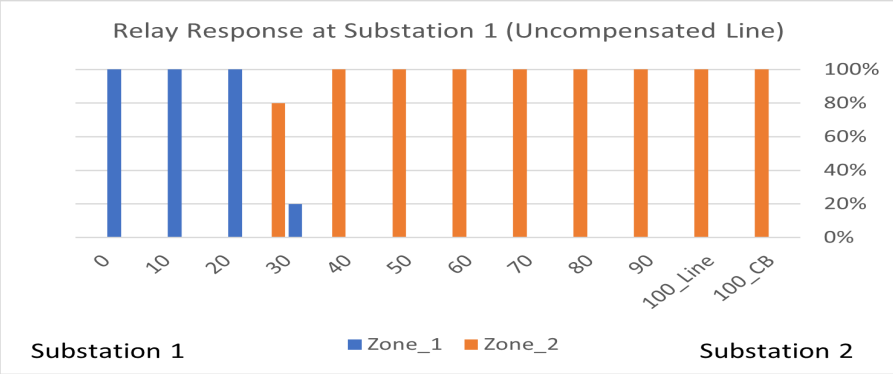


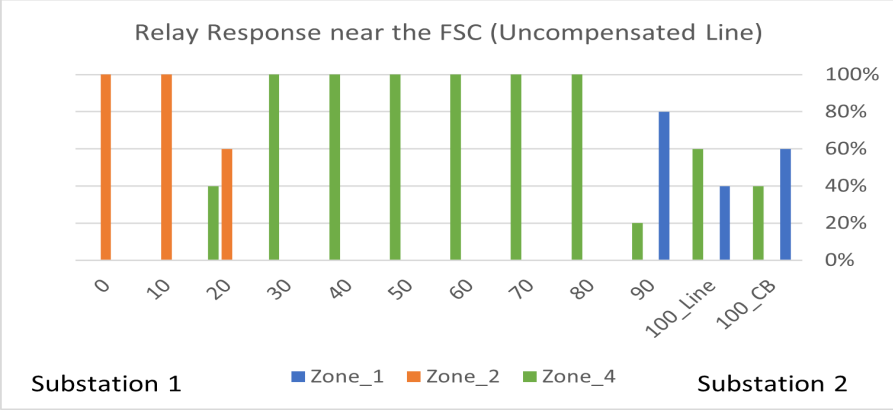


Dominion Energy

Simulation Results (FSC Bypassed)

- For Substation 1, the underreaching Zone 1 element reached up to 30%
- For Substation 2, the underreaching Zone 1 element reached up to 10% with gaps and the underreaching Zone 4 covered up 80% without gaps
- Remaining parts were protected by the overreaching element Zone 2

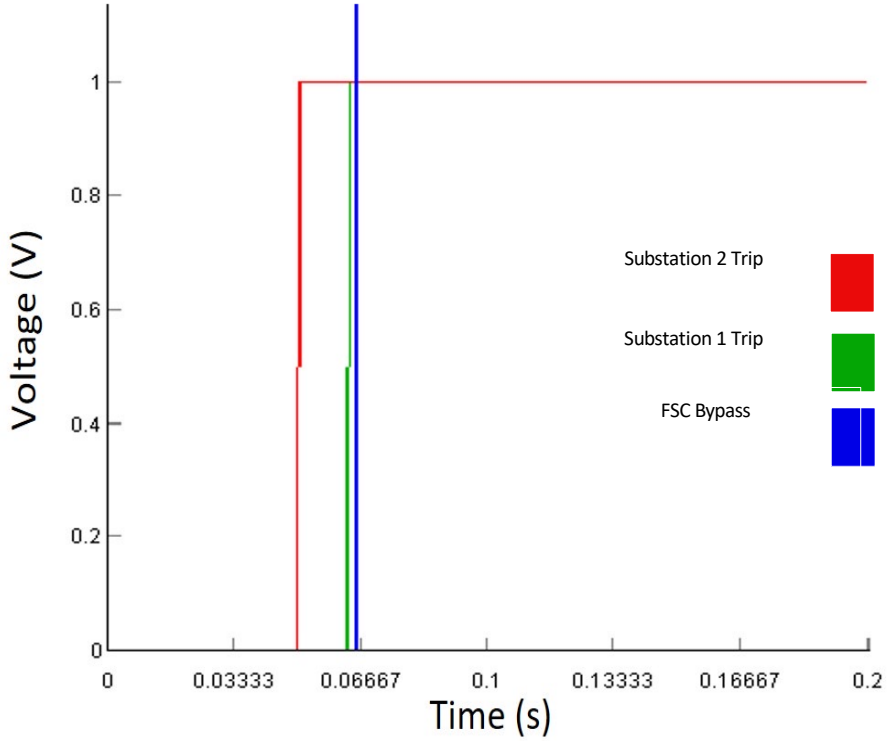




Dominion Energy

Simulation Results (Transient Response)

- For a fault near the FSC
  - Substation 2 relay trips (Zone 1)
  - Substation 1 relay trips (Zone 2)
  - Temporary Bypass the FSC
- FSC controller had a slower response time compared to the relays
  - This is because of the propagation delay of signals in the FSC controller
- Gaps in line protection are attributed to whether the FSC is bypassed or not



Dominion Energy

Results Analysis

- Since the FSC controller's response was slower than the relays' response, Zone 4 did not operate while the FSC was in-service
- Zone 4 can be activated when the FSC is bypassed in the case of repetitive faults
- We recommend maintaining the series-compensation logic with the options Y and XC = OFF selected to ensure fewer gaps in protection
- Zone 4 protection (when the FSC was bypassed) provided more protection than Zone 1 (when FSC was in-service) as we moved away from the FSC towards Substation 1

Contributions

- Identified the interaction between the FSC controller and the relays
- Analyzed the relays response for a batch of faults
- Provided recommendations for enhancing line protection
- Created models and test procedures for future in-house studies with integrated hardware-in-the-loop setup

Dominion Energy

Conclusion

- Batch of various faults generated data to explore different relay responses
- Series compensation logic in impedance relay is usually designed for internal faults protection, but it can cause gaps in protection
- FSC controller has a slower response time compared to relays
- The recommendation is to keep series compensation logic with Zone 4 active when FSC is bypassed
- Hardware-in-the-loop setup can be used for future R&D projects

Future Work

- Install Power Line Carriers in the hardware-in-the-loop setup
- Investigate the protection impact on nearby transmission lines

Acknowledgment

- My manager Katelynn Vance, Ph.D. and my mentor Andrea Pinceti, Ph.D.
- Hung-Ming Chou and Daniel K. Ridenour from Dominion Energy for their collaboration, and data-sharing proactivity
- Dominion Energy for the internship experience

Dominion Energy®

Thank you

Abdulaziz Qwbaiban
Qwbaiban@gatech.edu

Dominion Energy®

Questions?