TCR Magnetic Field Analysis

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Dominion Profile

Primary Operating Segments Overview

Dominion Virginia Power

Electric Transmission

- **6,400 miles** of transmission lines
- Favorable regulatory environment

Electric Distribution

- **57,000 miles** of distribution lines
- **2.5 million** franchise retail customer accounts in VA and NC

Dominion Energy

Gas Transmission

- Together with Gas Distribution, operates one of the largest natural gas storage system in the U.S.
- **10,900 miles** of pipeline in six states
- Well positioned in Marcellus and Utica Shale regions

Gas Distribution

- **21,900 miles** of distribution pipeline and **1.3 million** franchise retail natural gas customer accounts in OH & WV

Blue Racer Joint Venture

- Utica Shale midstream services

Dominion Generation

Utility Generation

- **19,600 MW** of capacity
- Balanced, diverse fuel mix
- Favorable regulatory environment

Merchant Generation

- **4,000 MW** of capacity, including nuclear, gas and renewable power
- Active hedging program for energy revenue/margins

Dominion Retail

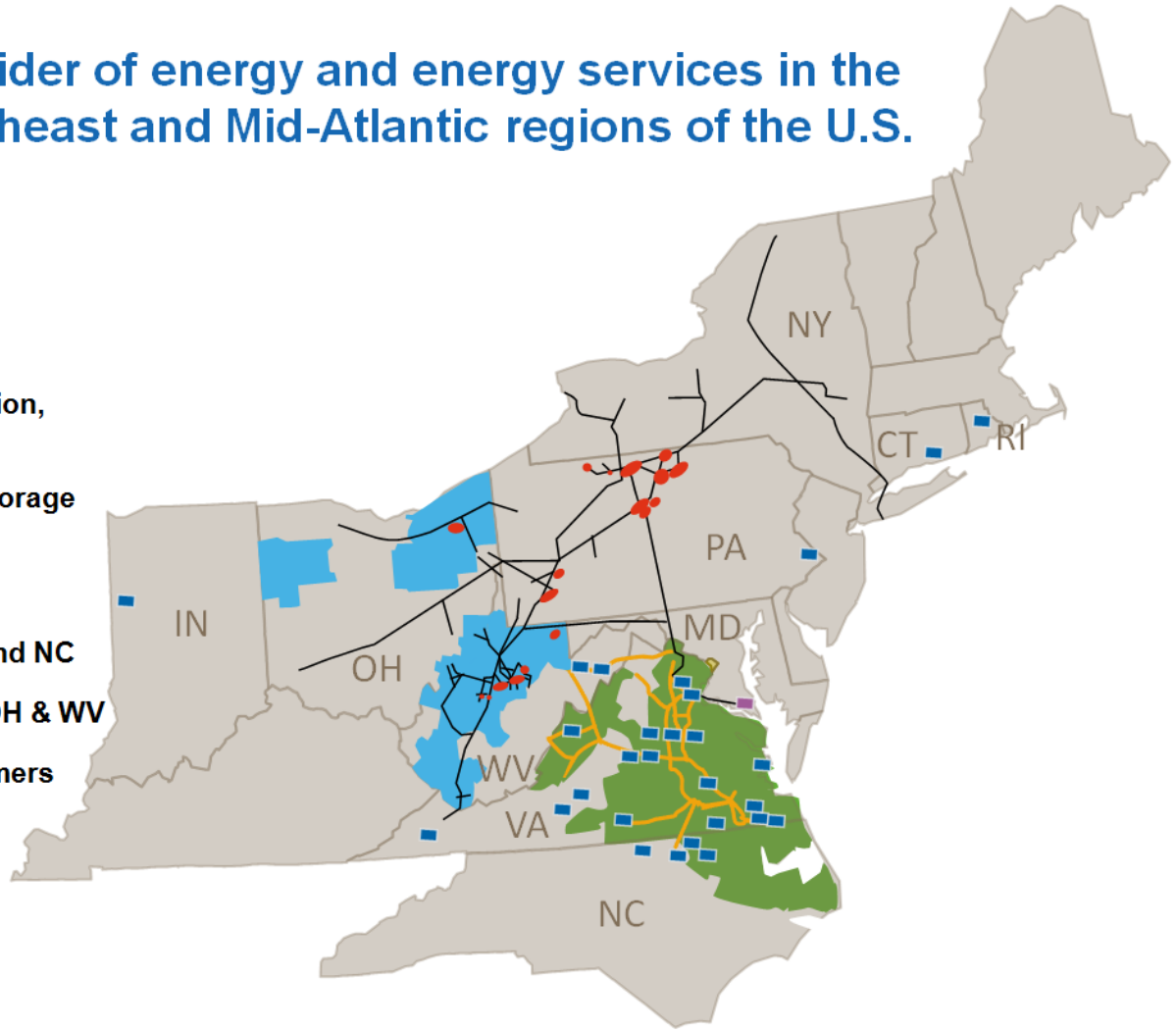
- Retail Gas & Products/Services
- **1.5 million** non-regulated customer accounts in **10** states*

Dominion Profile

Power and Natural Gas Infrastructure

Leading provider of energy and energy services in the Midwest, Northeast and Mid-Atlantic regions of the U.S.

- **23,600 MW** of electric generation
- **6,400 miles** of electric transmission
- **10,900 miles** of natural gas transmission, gathering and storage pipeline
- **947 billion cubic feet** of natural gas storage operated
- Cove Point LNG Facility
- **2.5 million** electric customers in VA and NC
- **1.3 million** natural gas customers in OH & WV
- **1.5 million** non-regulated retail customers in **10** states* (not shown)



Engineering Support Group

- **System Studies for Dominion**

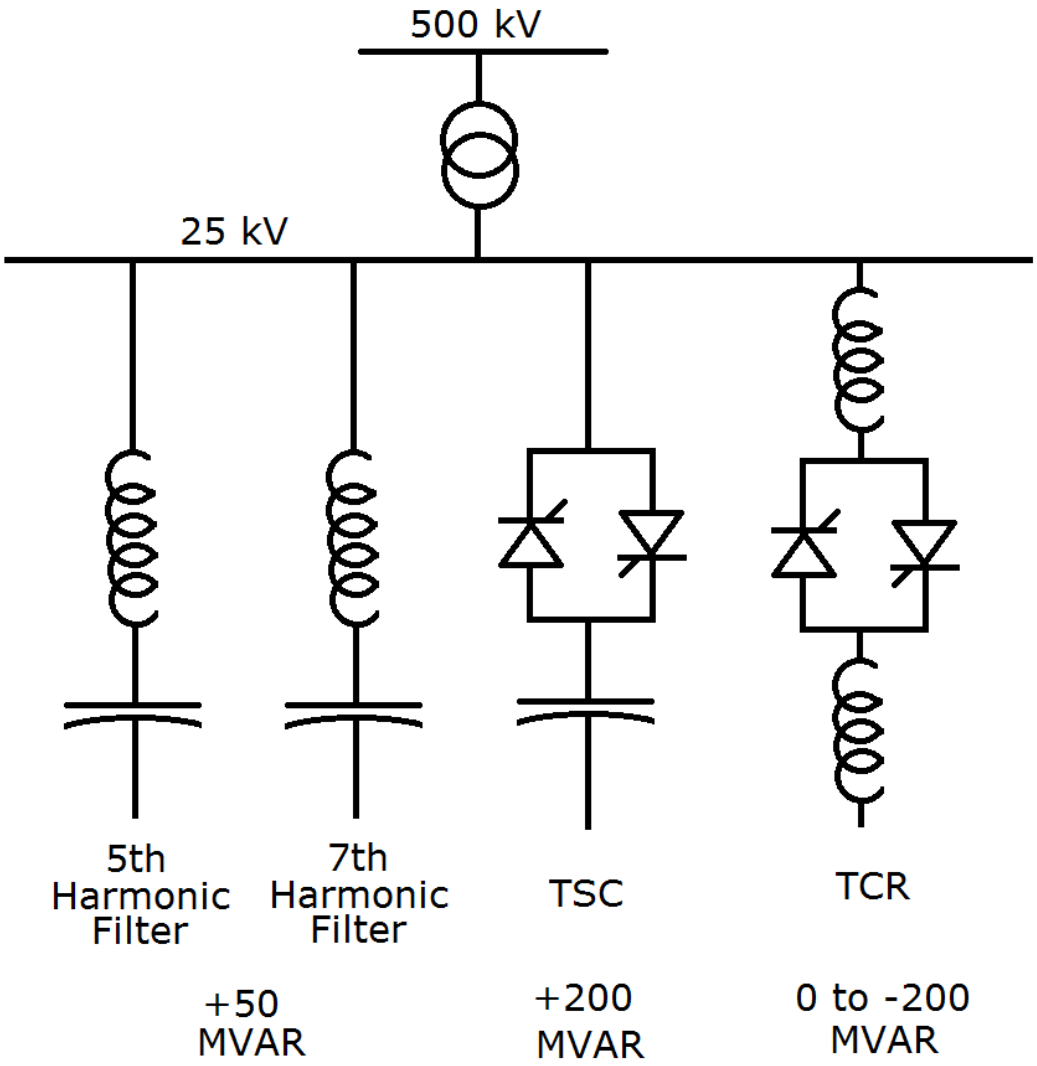
SVC

TCR Magnetic Field Study

SVC Requirement

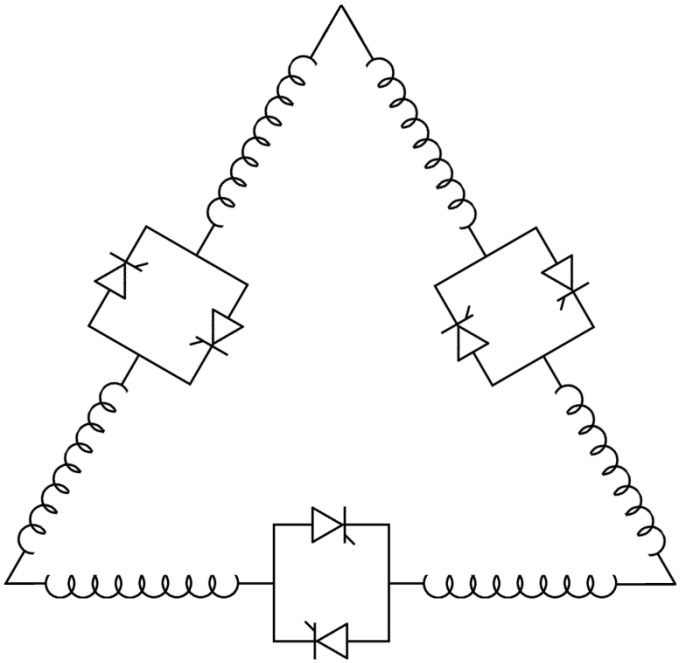
- **2 SVC installed in 2014**
- **Voltage recovery for transmission system disturbances**
- **Fast reactive power compensation for system undervoltages produced by system faults**
- **PJM Voltage Recovery Criteria**
  - **0.7 p.u. @ 20 cycles**
  - **0.9 p.u. @ 1 second**

Dominion SVC (-150/+250 MVAR)



TCR Function

- TCRs provide a variable inductance
- The MVAR output depends on the firing angle (α)
- Works with fixed cap banks and TSCs to provide exact amount to reactive power



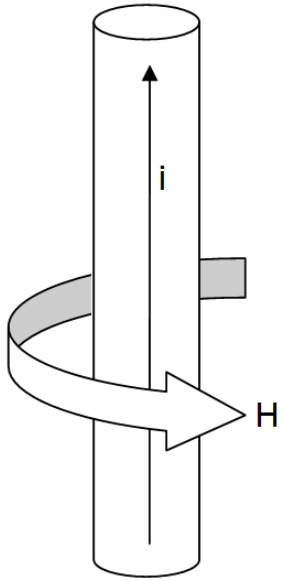
SVC TCR's

SVC Construction

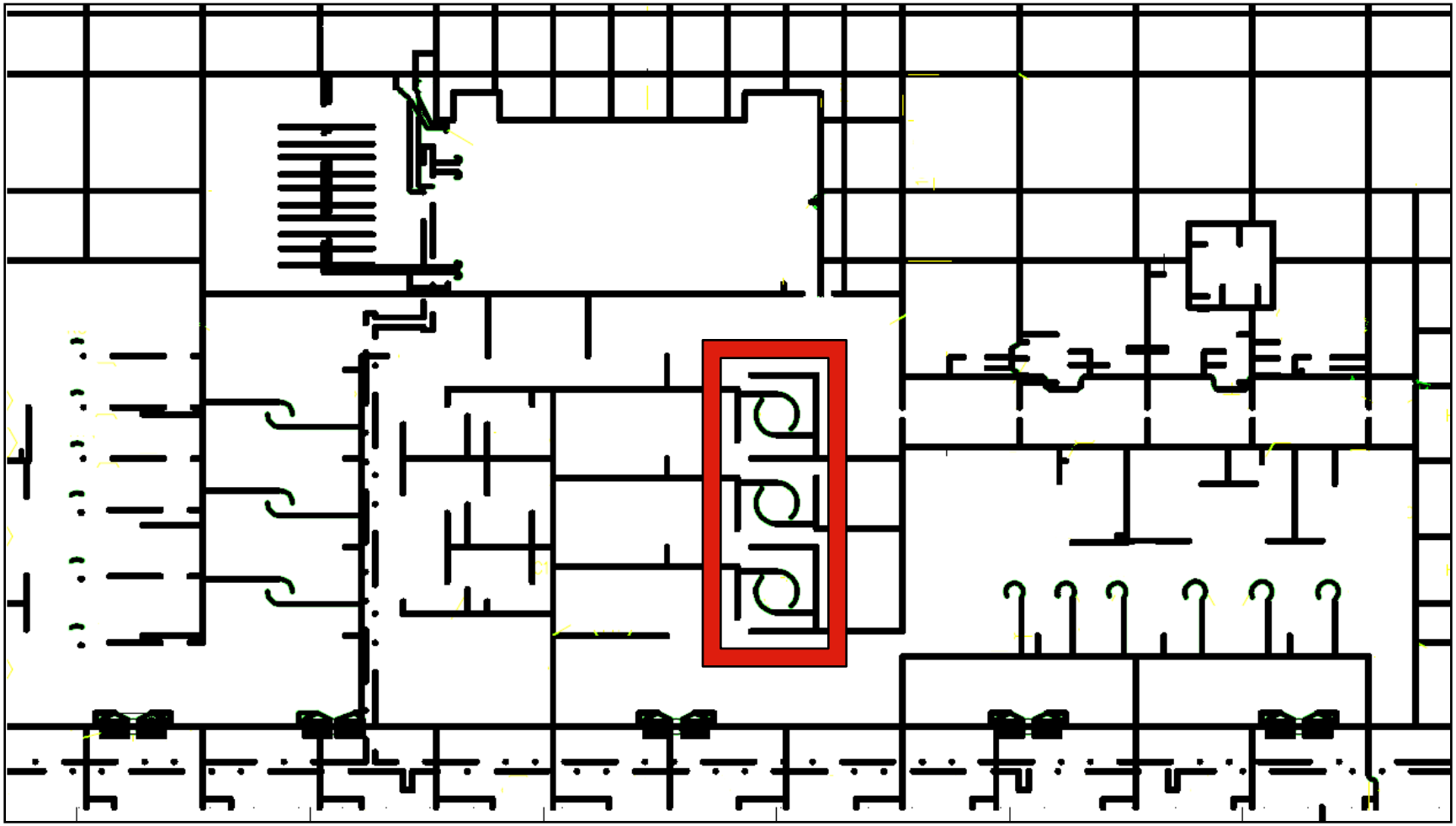
- Currents were measured in the ground grid of the substation during installation of the SVC
- Initial assessment indicated that the currents were present during the TCR operation
- A formal investigation was initiated to find the source of the circulating currents

Magnetic Fields

- **Magnetic field is produced when a conductor carries current (2667 amps).**
- **A TCR is a winding capable of producing magnetic fields (N*i).**
- **TCR model in Maxwell 3D**



Ground Grid Diagram

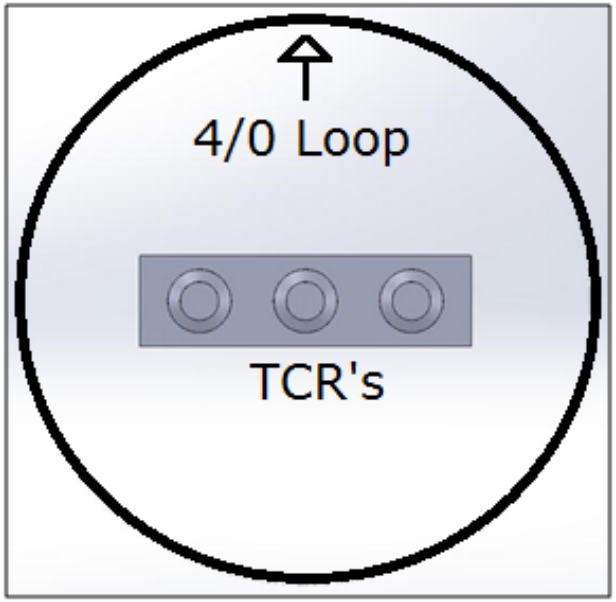


Simulation Approach

- ANSYS Maxwell 3D simulation software
- Eddy current solver was chosen due to its capability to calculate AC magnetic fields
- Ground Grid replaced by a copper ring
- The TCR's were simulated at full power output of 200 MVAR (2667 Amperes)

TCR Simulation

- Copper ring of ½ inch diameter simulation a 4/0 copper ground wire
- Magnetic fields and induced currents were calculated at ground level and 8 feet above ground

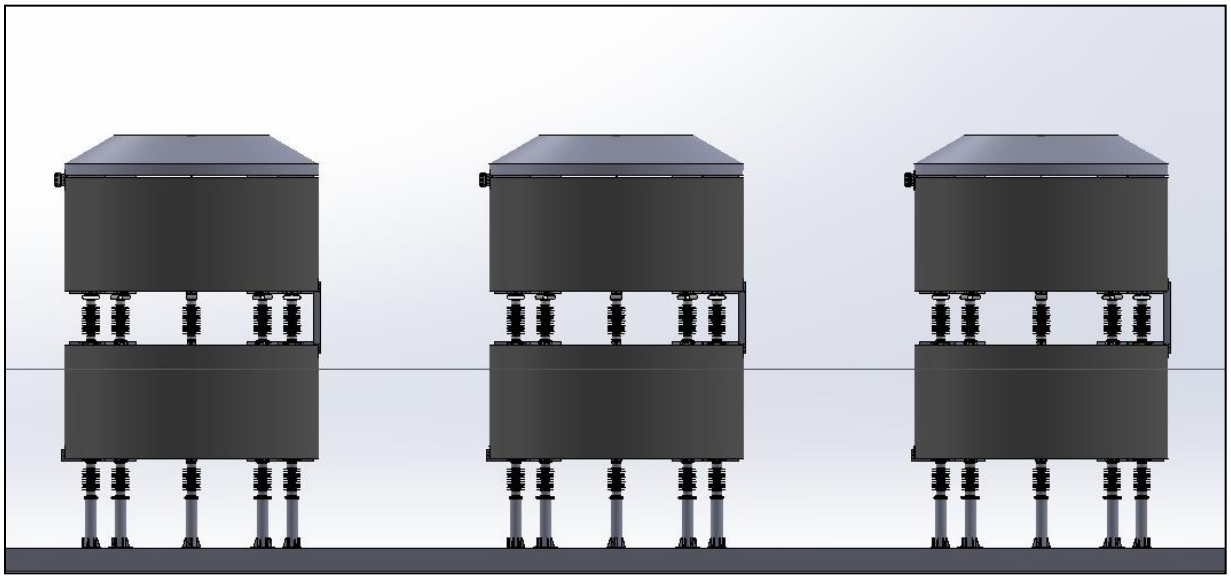


Reactor Arrangement

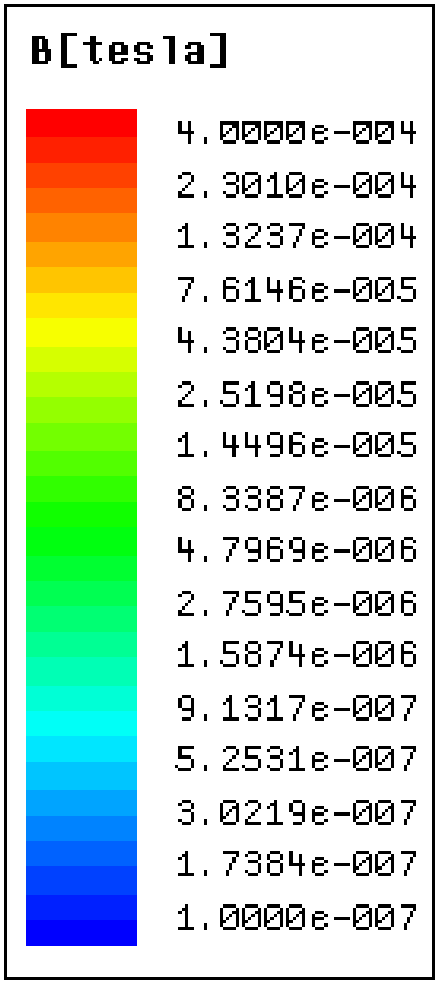
Flat Design	Delta Design
	

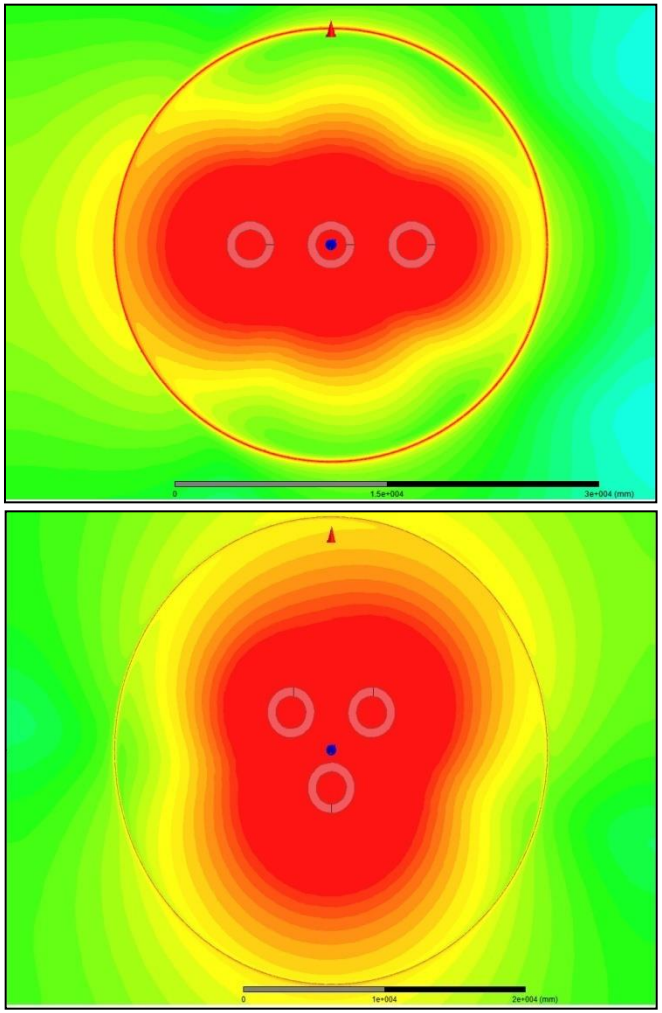
Magnetic Field Study

- **Model was built by Abhijeet Gujrati, a University of Pittsburgh Graduate Student during a summer internship**



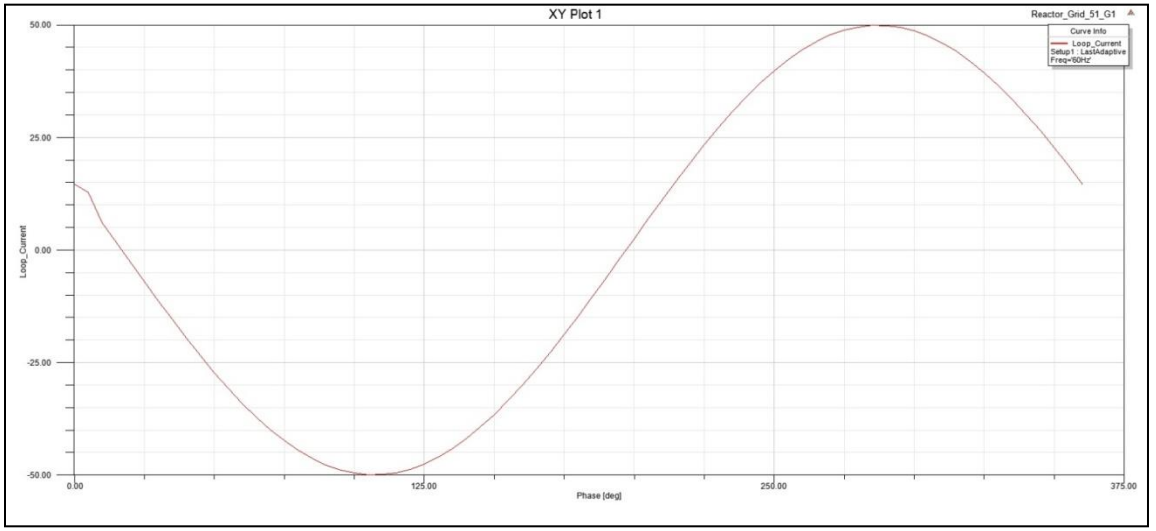
Magnetic Field Plots



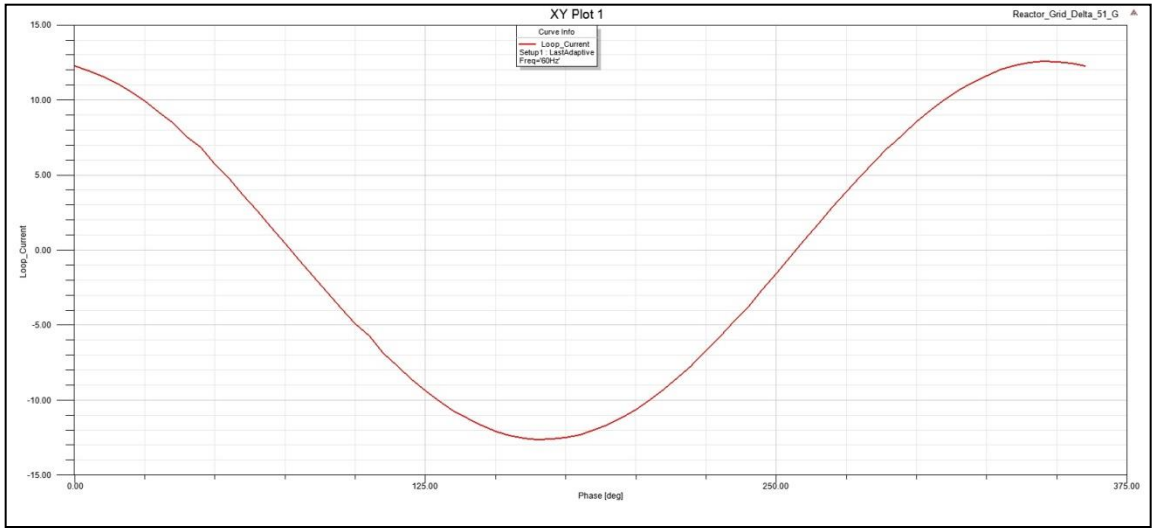


Currents in Copper Loop

- **Flat Design 50 Amps**



- **Delta Design 13 Amps**



Simulation Results

#	Model	Current in the 4/0 wire
1	Flat design 51 feet radius 8 feet above ground	76 Amperes
2	Flat design 51 feet radius 0 feet above ground	50 Amperes
3	Flat design 60 feet radius 0 feet above ground	35 Amperes
4	Delta design 51 feet radius 8 feet above ground	20 Amperes
5	Delta design 51 feet radius 0 feet above ground	13 Amperes
6	Delta design 60 feet radius 0 feet above ground	8 Amperes

Conclusion

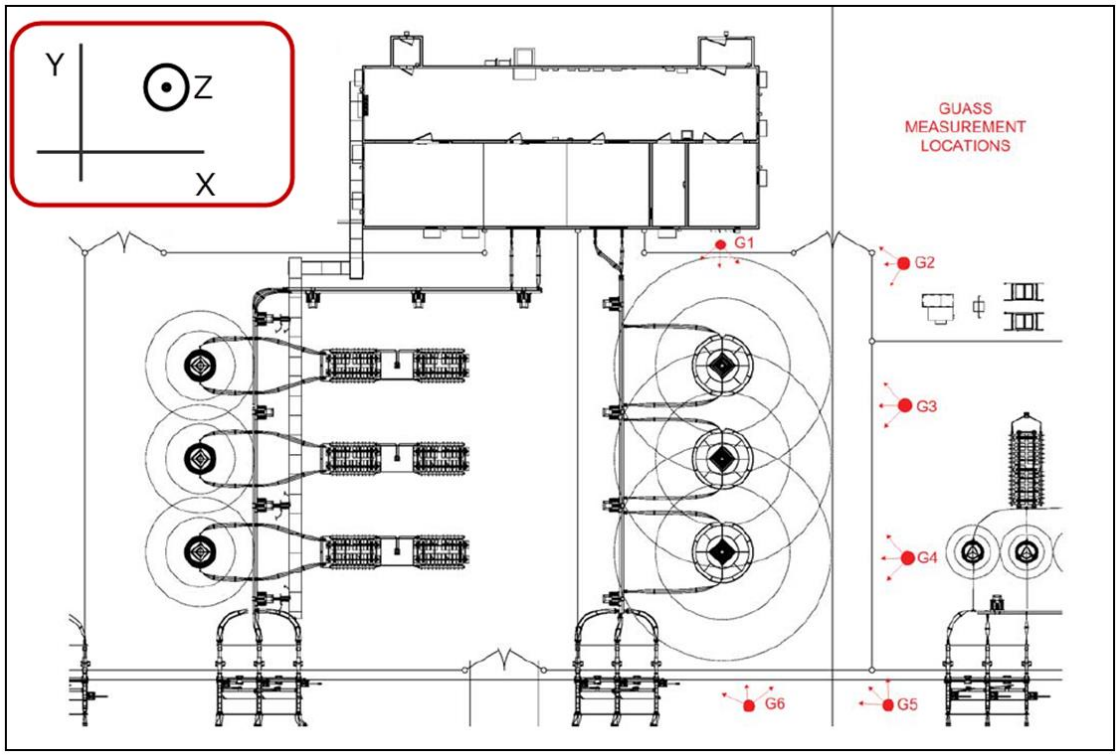
- Delta design currents are ~¼ of the flat design. (Inductance needs to be verified)
- 9 feet of extra clearance reduced currents to ~65% in simulations
- Single Point Grounding
- Avoid conductive loops near the TCR's
- Add magnetic clearance distance between reactors and closed conductive loops

TCR Magnetic Field Analysis

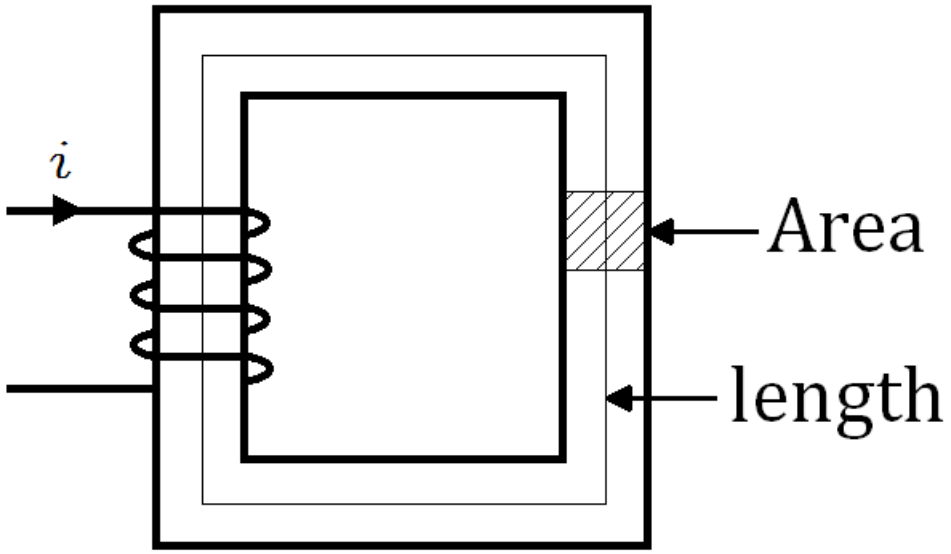
Questions?

Comparison to Field Measurements

- **G1 Measured:920 milli Gauss (Z component)**
- **G1 Simulation: 800 milli Gauss (Z component)**



Future Work: Inductance Change



$$Inductance = \frac{N^2}{\text{length}/\mu * \text{Area}}$$