# Topology Control Analysis Mitigations for Geomagnetically Induced Currents


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## Introduction

Geomagnetic disturbances (GMDs) are caused by corona mass ejections from the sun. These solar corona mass ejections can cause changes in the earth's magnetic field, which in turn produces non-uniform electric fields. These GMDs have the ability to disrupt the electric grid by causing quasi-dc, geomagnetically induced currents (GICs) in the high voltage transmission grid.

## Importance

The 2015 National Space Weather Action Plan released by the White House of the United States called for protection, mitigation, response, and recovery from potential devastating effects of space weather for the reliability of electric power. GICs have the ability to severely disrupt the operations of our power system:

- Permanent damage to critical assets – high-voltage transformers due to overheating
- Voltage collapse and a large-scale blackout – the loss of reactive power support in our transmission lines

## Aim

One specific area of interest is the mitigation of GICs by topology control analysis (TCA). TCA is used on a daily basis to optimally dispatch the network topology along with generation resources, which has the ability to bypass significant congestion costs on the system and increase transfer capability. Research shows that implementing a specific TCA can also have the ability to reduce reactive power losses, which in turn can help prevent a voltage collapse and a large-scale blackout.

With an appropriate model system, various topology control algorithms can be applied to determine the optimal solution for mitigating GICs. The algorithm structure creates the switching criteria and reiterates until an improved, feasible solution is created and the stopping criteria is met. The economic topology control uses the following stopping criteria:

- Feasibility – all demand must be supplied with no transmission overloads
- Security – system is credible N-1 contingency secured
- Connectivity – no electrical islands are created
- Cost Reduction – feasible dispatch of lower out-of-merit costs
- Minimal Computational Effort – algorithm must be real-market setting applicable

## Algorithm

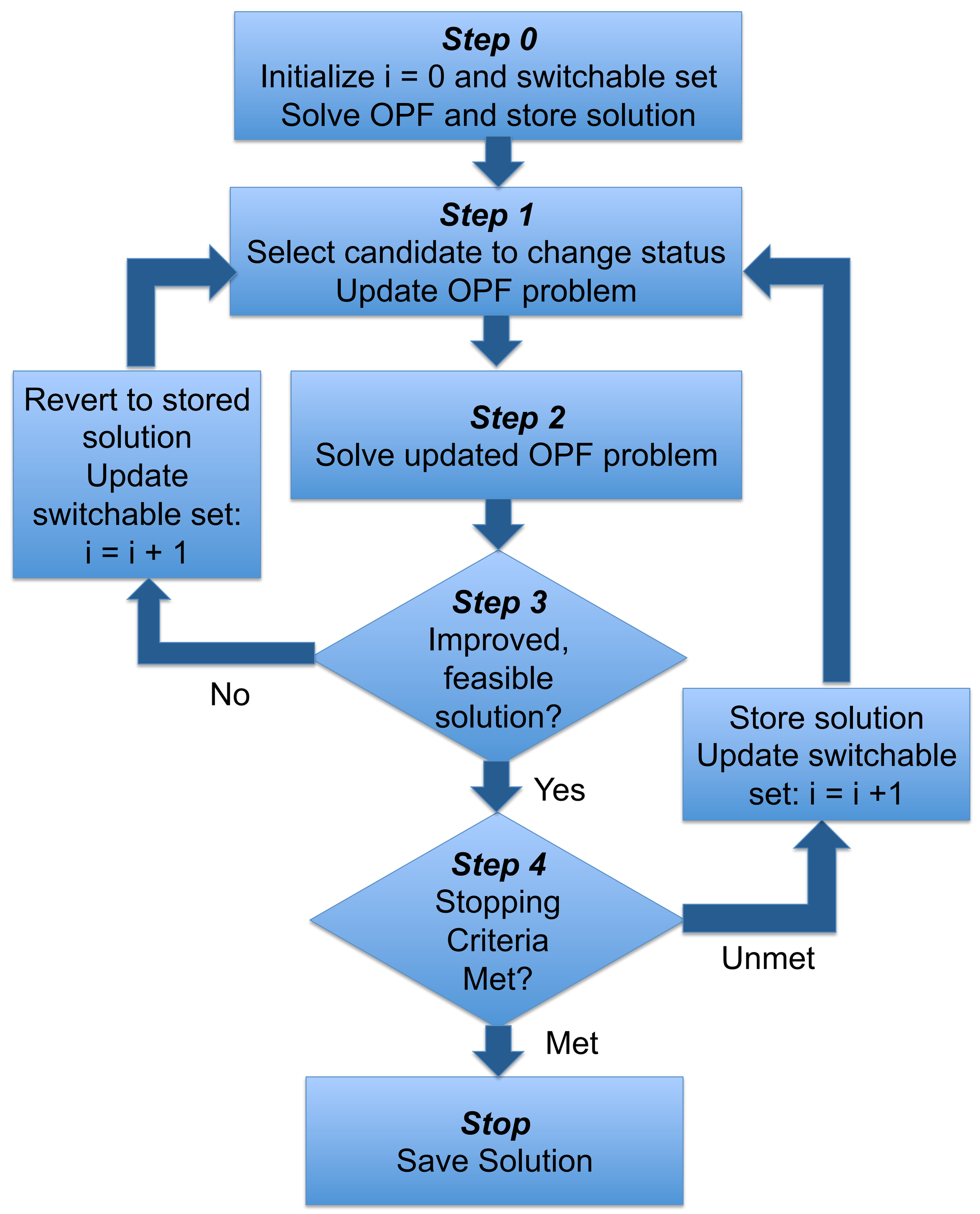


**Figure 1.** Flow chart of economic topology control algorithm

## Sensitivity Analysis

Topology control analysis can be based on various sensitivity-based switching criterions, which ultimately compute different metrics and determine an optimal solution through iteration. The information behind selecting the lines for the sensitivity-based switching criterions is readily available from the economic dispatch. Commonly used sensitivity-based switching criterions include:

- Line Profits – selects the most unprofitable line in the switchable set as a candidate for opening
- Price Difference – selects the most unprofitable line with the largest price difference as the candidate for opening
- Total Cost Derivative – selects the line with most negative total cost derivative impacts as the candidate for opening
- Weighted Total Cost Derivative – selects the line with most negative total cost derivative impacts, multiplied by the portion of flow that does not go through that line for transactions between terminal nodes of that line as the candidate for opening

## Simulation

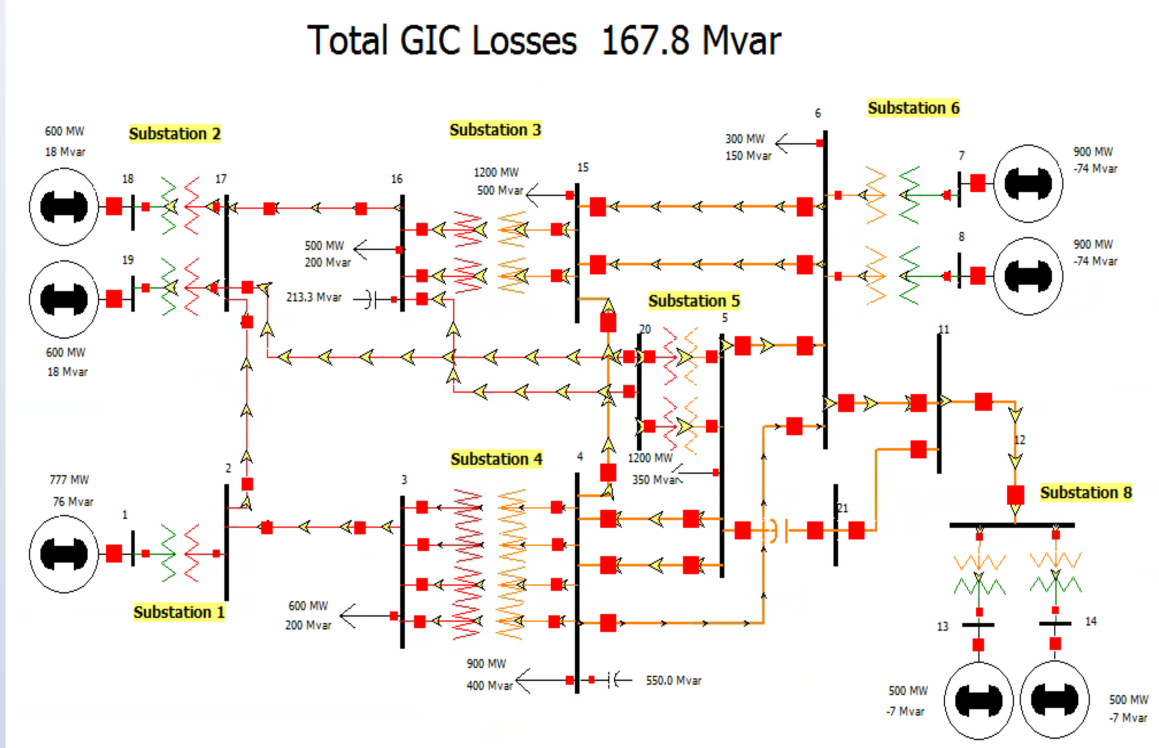


**Figure 2.** GIC test case [4] on PowerWorld Simulator [3]

## Results

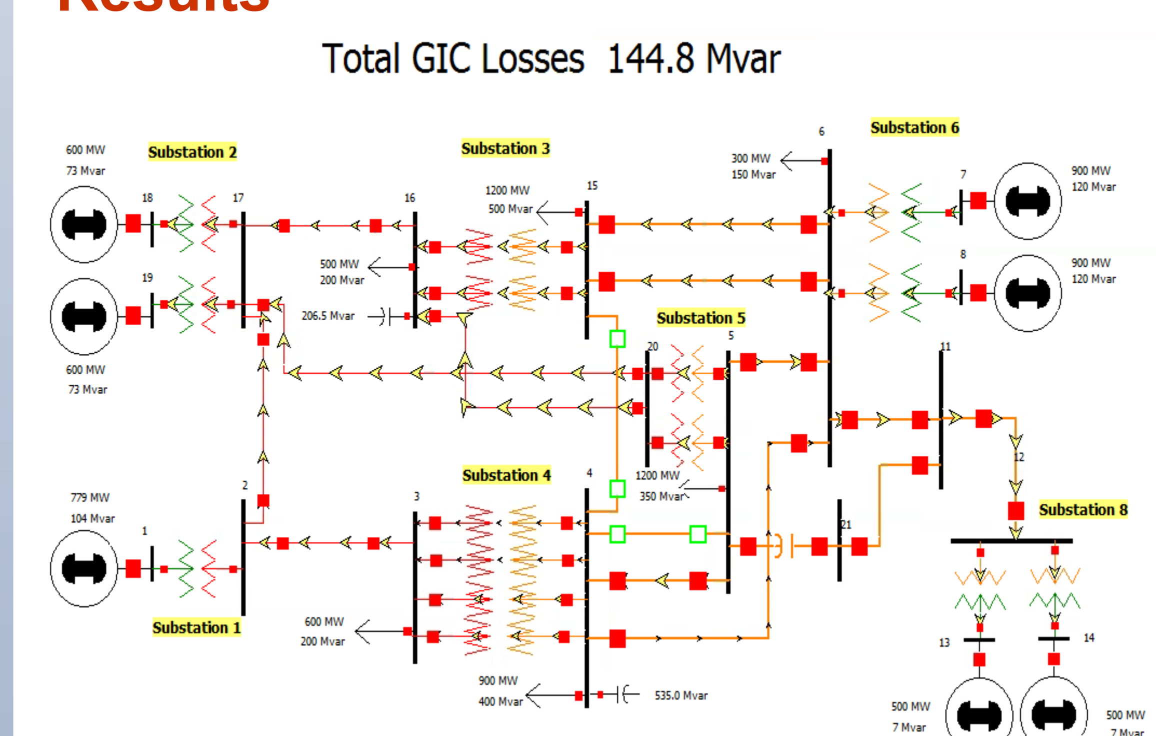


**Figure 3.** Beginning of algorithm process on GIC test case

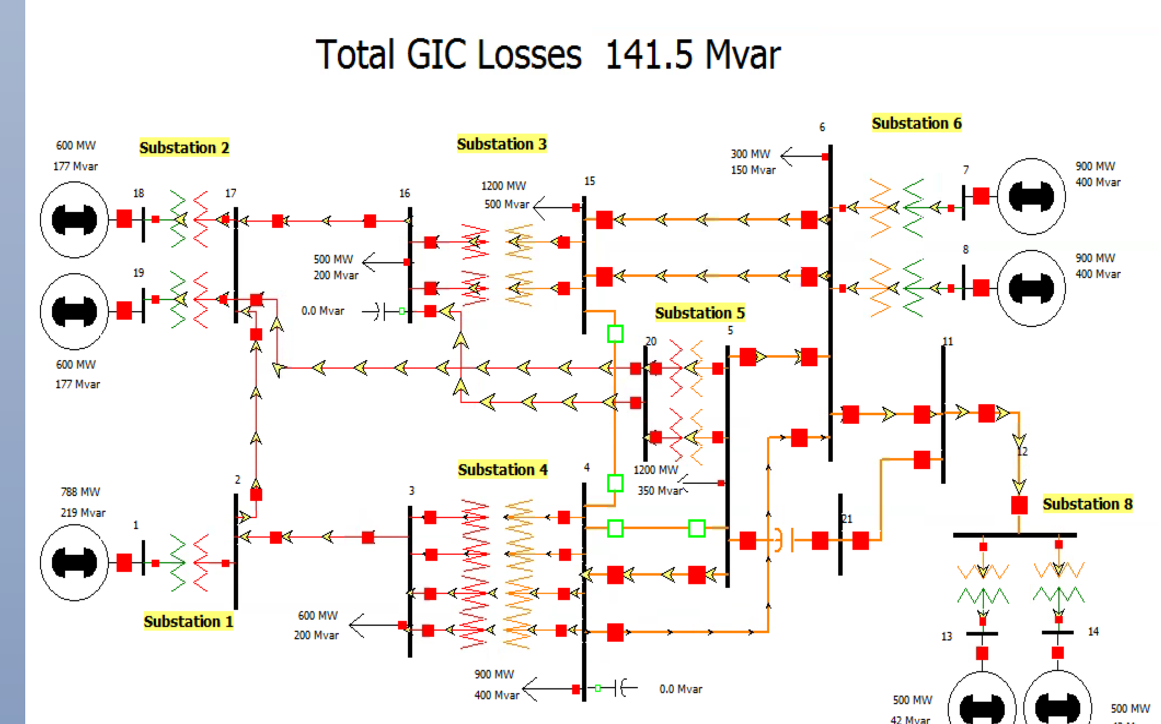


**Figure 4.** Optimal solution for GIC test case

**Table 1.** Optimal topology for GIC test case

| Element Removed | Location |
|---|---|
| 500kV Transmission Line | Bus 4 to Bus 15 |
| 500kV Transmission Line | Bus 4 to Bus 5 |
| 550Mvar Shunt Capacitor | Bus 16 |
| 213.3Mvar Shunt Capacitor | Bus 4 |

## Conclusions

Evaluating the GIC test case through the economic topology control algorithm was optimally solved as shown in Table 1. The following trends were evaluated while determining the optimal solution for the GIC test case:

- Disconnecting all shunt capacitors on the system decreased total GIC losses
- High-voltage lines significantly decreased total GIC losses in comparison to low-voltage lines
- Transmission lines were more effective in lowering total GIC losses than other system equipment

An analysis [2] between the four sensitivity algorithms (line profits, price difference, total cost derivative, and weighted total cost derivative) summarized that the optimal policy applied doesn't need to open optimal lines, but rather the lines with similar characteristics:

- Low flows
- High connectivity
- Negative price differences

With this, the greatest cost reduction is brought by the status change of a few switches through lines with the above characteristics. This resembles the optimal solution characteristics determined through the GIC test case.

## Acknowledgements


**Faculty Mentor:** Hao Zhu
**Funding and Support:** Grainger Center for Electric Machinery and Electromechanics


## References


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[3] PowerWorld Simulator Version 18. [Online]. Available: http://www.powerworld.com/
[4] EPRI PowerWorld Simulator Case with Dynamics and Induction Motors, Feb 16, 2013.


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