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Title: Optimal Transmission Line Switching under Geomagnetic Disturbances

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OPTIMAL TRANSMISSION LINE SWITCHING UNDER GEOMAGNETIC DISTURBANCES

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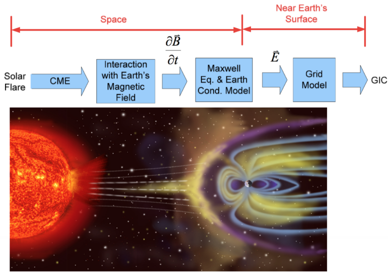
Geomagnetic Disturbance



Solar flares and coronal mass injections cause Geomagnetic Disturbances (GMDs) which lead to abrupt changes in the Earth's magnetic field, inducing voltage potential at earth's surface and quasi-dc currents (GICs).

Historical occurrences:

- The Carrington Event of 1859
- The 1921 Solar Storm
- The 1989 QueÌĄbec Blackout
- The 2003 Halloween Solar Storms

GMD impacts on grids

During GMD, GIC can enter and exit the power system at transformer grounds and cause half-cycle saturation of transformers, resulting transformer hot-spot heating. Further, it increases reactive power losses which can disrupt the normal operation of power systems and, in some cases can, severely damage transformers.

Goals

Develop and solve an optimization model to integrate the AC Power Flow constraints with the effects of GMD on the transmission grid, modeling

- transformer hot-spot heating
- increased reactive power losses

and to mitigate such devastating effects with an option of **"transmission line switching"**

Optimal transmission line switching under GMD

Parameters

$\mathcal{N}$: set of buses; $\mathcal{E}$: set of lines; $\mathcal{E}^{\tau}$: set of transformer lines; $\mathcal{E}^{g}$: set of dummy lines; η^0_{ij}, η^1_{ij} and η^2_{ij}: coefficients of the thermal GIC capability curve of a transformer line; K_i: transformer specific scalar at bus i; 0 if no transformer is located.

Variables

x_{ij}: determines if line ij is switched on/off; I^a_{ij}: alternating current magnitude on line ij; V^d_i: GMD-induced DC voltage at bus i; I^d_i: GIC magnitude at bus i; v_i: voltage at bus i; Q^{loss}_i: induced reactive power loss at bus i.

Minimize generator dispatch costs + load shedding costs

s.t. AC power flow equations with an option of switching lines

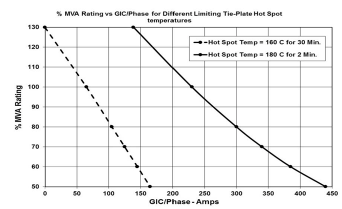
AC power flow nodal balance constraints

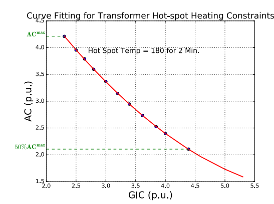
Operational limit constraints

$x_{ij}, I^a_{ij} \in$ **GMD constraints**

GMD constraints

- GIC modeling
- Transformer hot-spot heating





- Given hot-spot temperature for all transformers, a 2^{nd} order polynomial fit of AC current flow I^{AC}_{ij} as a function of induced GIC magnitude I^d_i.
- Feasible region for AC current flow is given by:

$$I^{AC}_{ij} \le \eta^0_{ij} + \eta^1_{ij} I^d_i + \eta^2_{ij}(I^d_i)^2 \quad \forall (ij) \in \mathcal{E}^{\tau}$$

- Induced reactive power losses

$$Q^{loss}_i = K_i v_i I^d_i \quad \forall i \in \mathcal{N}$$

Case study

- Modified single area IEEE RTS-96 system
  - 57 buses, 71 lines, 33 generators, 38 transformer lines
- The optimization model was implemented in Julia/JuMP and solved using CPLEX 12.6.2

References

† DTRA code: HDTRA-R-3774-09-0

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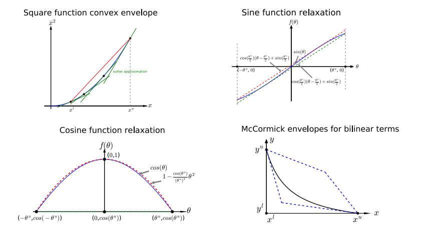
Challenges

- Discrete variables - NP hard
- Non-linear, non-convex constraints
  - Disjunctive AC power flow
  - Induced GMD

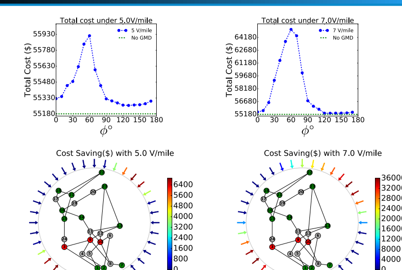
Convex relaxations

$$p_{ij} = x_{ij}(g_{ij}V_i^2 - V_iV_jg_{ij}\cos(\theta_{ij}) - V_iV_jb_{ij}\sin(\theta_{ij})) \ \forall ij \in \mathcal{E}$$

$$q_{ij} = x_{ij}(-(b_{ij} + \frac{b^c_{ij}}{2})V_i^2 + V_iV_jb_{ij}\cos(\theta_{ij}) - V_iV_jg_{ij}\sin(\theta_{ij})) \quad \forall ij \in \mathcal{E}$$



Results



	Optimality Gap(%) from AC feasibility		
Strength	Mean	Min	Max
5 v/mile	0.34	0.062	1.00
7 v/mile	0.69	0.054	1.00

Future work

- Stochastic events
  - For known characteristics of the event
  - Models with space weather predictions
  - Robust operations
- Scalability to larger networks with intensive GMDs