Investigating the Impact of Communication Loss on Power Grid Stability during a Large Disturbance

Massachusetts Institute of Technology

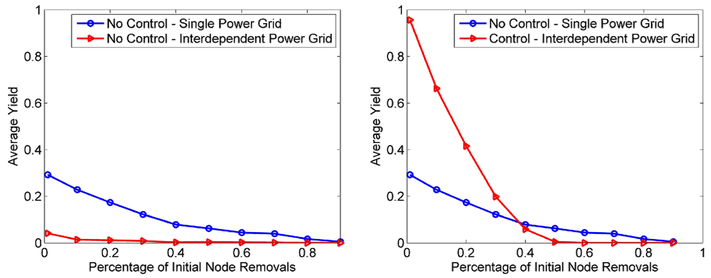
Marzieh Parandehgheibi, Konstantin Turitsyn and Eytan Modiano

(marp,turitsyn,modiano@mit.edu)

LIDS

Introduction

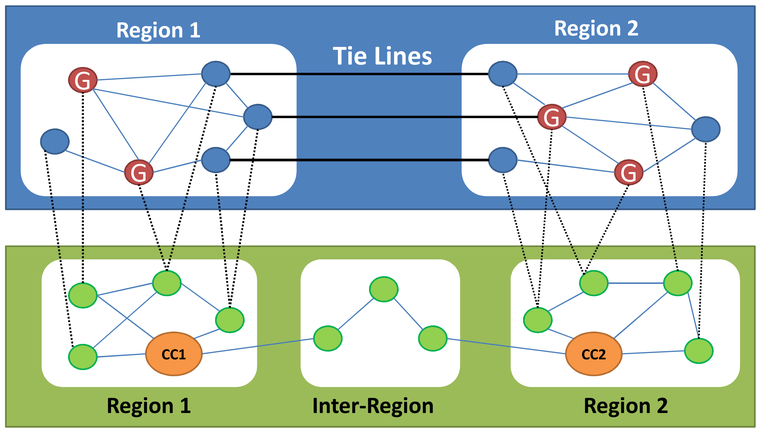
- In order to avoid large cascading failures, a communication network is required for online monitoring & control
- Power grid and communication network make a strong interdependency
- Literature suggests that interdependency makes networks more vulnerable
- A proper analysis of interdependent networks should account for the availability of control schemes applied by the communication networks



Interdependency increases the robustness of power grid

Question:
A point-wise failure model seems too simplistic.
How does the loss of communication network impact the power grid?

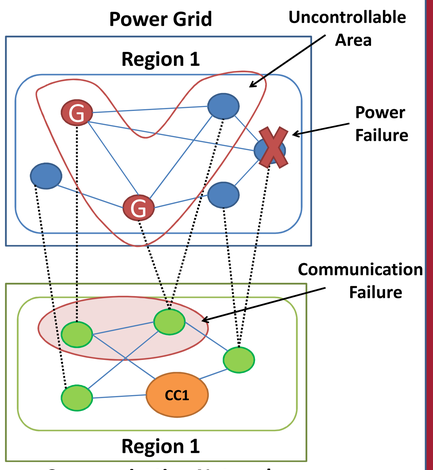
Ideal Model of Communication Network Responsible for Wide-Area Control



Types of Communication Failures:
- **Intra-Region**
- **Inter-Region**

Intra-Region Failures:

1) Uncontrollable area and power failures are **disjoint**:
   - Complete Information about the last state of Grid
   - Partial Control
2) Uncontrollable area and power failures **overlap**:
   - Incomplete Information about the state of Grid
   - Partial Control



Role of Communication Network

Information collected by Communication Network

$V_k(t)$	Magnitude of voltage at node k
$\theta_k(t)$	Phase of voltage at node k
$\omega_k(t)$	Frequency of Power at node k
$f_{kj}(t)$	Flow in power line (k,j)

Control Actions

Centralized Control Requires Communication	**Decentralized** control-protection Performs locally- No Need to Communication
Ramping down generators	5% droop control at generators
Intelligent load shedding	Over-frequency generator tripping (protection)
Intelligent line tripping	Under-frequency load shedding (protection)
	Overloaded line tripping (protection)

Full Control Model

$$\min \sum_{i \in V_L} PL_i$$

$$\sum_{j \in E} f_{ij} - \sum_{j \in E} f_{ji} = PG_i - \alpha_i(\omega_i - \omega_s) \quad \forall i \in V_G$$

$$\sum_{j \in E} f_{ij} - \sum_{j \in E} f_{ji} = PL_i \quad \forall i \in V_L$$

$$\sum_{j \in E} f_{ij} - \sum_{j \in E} f_{ji} = 0 \quad \forall i \in V_B$$

$$-M(1-z_{ij}) \le X_{ij} f_{ij} - \Delta\theta_{ij} \le M(1-z_{ij}) \quad \forall (i,j) \in E$$

$$-z_{ij} f_{ij}^{\max} \le f_{ij} \le z_{ij} f_{ij}^{\max} \quad \forall (i,j) \in E$$

$$-M(1-z_{ij}) \le \omega_i - \omega_j \le M(1-z_{ij}) \quad \forall (i,j) \in E$$

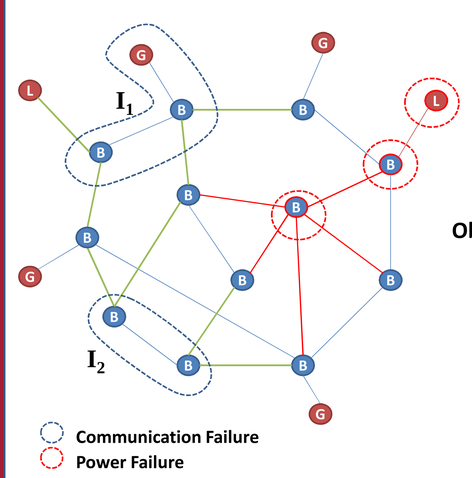
$$\omega_i^{\min} \le \omega_i \le \omega_i^{\max} \quad \forall i \in V_G$$

$$PG_i^{\min} \le PG_i \le PG_i^{\max} \quad \forall i \in V_G$$

$$PL_i^{\min} \le PL_i \le PL_i^{\max} \quad \forall i \in V_L$$

$$z_{ij} \in \{0,1\} \quad \forall (i,j) \in E$$

Partial Control Model



Controllable Areas: Full control

Uncontrollable areas:
1. Switch the Generators and Loads to a predefined strategy for CommLossMode;
2. Allow Trip border lines

Objective: Stabilize Grid
a) Minimize Load Shedding while keeping the nodes in the uncontrollable area at a predefined strategy
b) If keeping an uncontrollable area connected to the rest of grid is not feasible or costs a lot: Trip all border lines

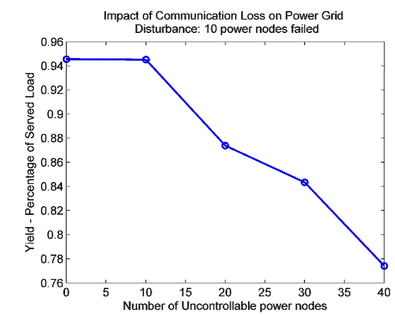
Simulation Results

- **Metric:** Yield (Percentage of served load)
- **Pre-defined Strategy:** The state of power nodes after disconnection from the communication network

1) **P_{init}:** Keep the generators and loads at their last state
2) **P_{zero}:** Trip the generators and shed the loads

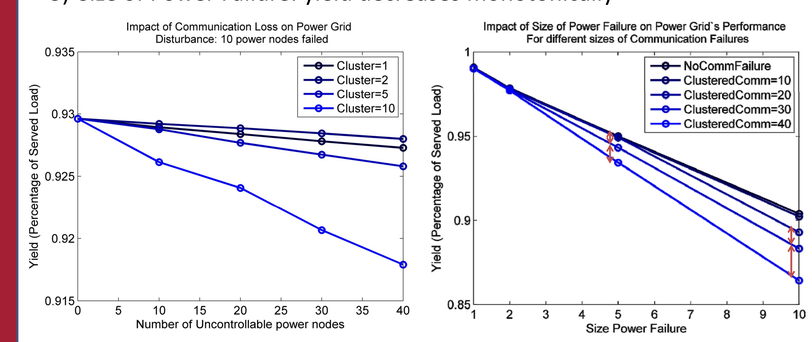
Observations:

➢ Communication loss makes network more vulnerable (smaller yield)



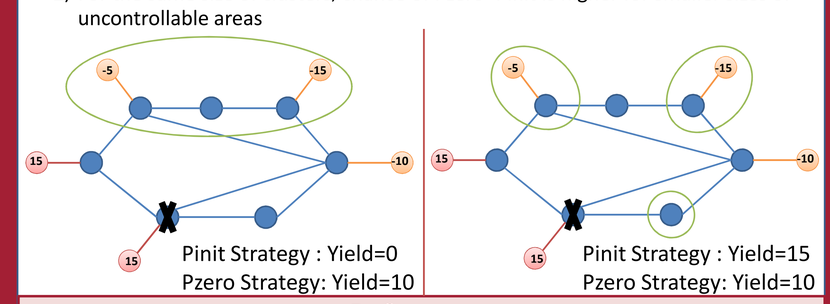
6% load shedding due to power disturbance
17% load shedding due to communication loss

➢ Impact is a function of several parameters such as:
1) size of uncontrollable area: yield decreases monotonically
2) size of uncontrollable clusters (topology of uncontrollable area)
3) Size of Power Failure: yield decreases monotonically



➢ Nodes both inside and outside the uncontrollable area could be affected

➢ P_{init} is <u>not</u> always better than P_{zero}
1) For the same size of uncontrollable area, chance of Pzero>Pinit is higher in clustered areas
2) For the same size of clusters, chance of Pzero>Pinit is higher for smaller sizes of uncontrollable areas



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1) Buldyrev, Sergey V., et al. "Catastrophic cascade of failures in interdependent networks." *Nature* 464.7291 (2010): 1025-1028.
2) Parandehgheibi, Marzieh, Eytan Modiano, and David Hay. "Mitigating cascading failures in interdependent power grids and communication networks."*Smart Grid Communications (SmartGridComm), 2014 IEEE International Conference on*. IEEE, 2014.

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