TCIPG

Trustworthy Cyber Infrastructure for the Power Grid

Decentralized Sensor Networking Models and Primitives for Smart Grid
Part I: Metrics of Grid Vulnerability to Cascading Failures
Part II: State-Aware Distributed Database Systems

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Overview and Problem Statement

Enhanced measuring/monitoring systems can improve grid security and resilience. This project is focused on data use and data management for Smart Grid applications.

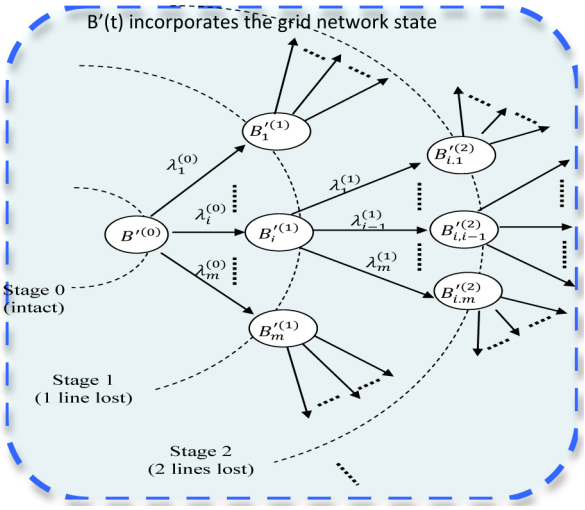
Research Objectives

Our specific objectives are as follows:

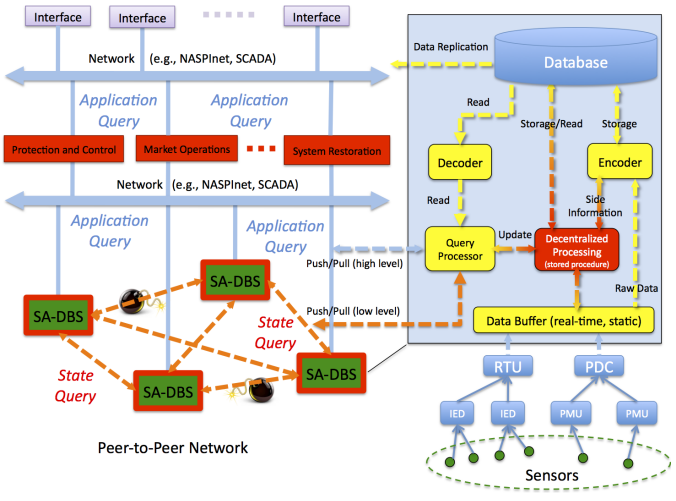
1. Regarding the use of Smart Grid data, we derived metrics that gauge the vulnerabilities of the grid that are based on first- and second-order statistics of the line flows.
2. Considering the problem of managing large amounts of sensor information, we proposed a scalable decentralized (peer-to-peer) architecture to store, process, and deliver the data reliably and rapidly. The key idea is to exploit the structure of the data and the class of queries that are typical of cyber-physical systems (CPS).

Technical Description and Solution Approach

Part I – Metrics of grid vulnerability to cascading failures: We have developed a stochastic model to study cascading failures in power grids. In our model, the grid state is conditionally Markovian, given a certain line flow. The transition rates of the line from the on to off state depend on the sojourn time of the line flow above the overload threshold of the line switch. We used the statistics of the sojourn time of line flows, derived from a Gaussian model, to obtain the expected active time of the line. These expected times provide a metric of the risk of cascading failures and also the time margin to perform corrective action. In our study, we derived the first- and second-order statistics of the flows from a DC power flow model applied to the load and generation data. However, in the future, we plan to use flow measurements and sensor data to compute the metric online directly.



Part II – State-aware distributed database systems: The Smart Grid is going to produce an enormous amount of data that stream continuously from the sensors to the database that is set to contain them. The management of this database is a critical problem, since the integrity and accessibility of the data are a potential bottleneck for putting them to good use. We have investigated how to further develop the concept of peer-to-peer (P2P) architectures to specifically address the needs of the power grid cyber-physical infrastructure. P2P architectures are generally more scalable and resilient than the centralized client-server architectures. The new architecture we propose for streaming P2P



Database Systems (DBS) that will be generally useful for Cyber-Physical Systems (CPS) is called "State-Aware" Distributed DBS (DDBS). The SA-DDBS comprises a stored routine for decentralized state estimation and a data representation and archival model that utilizes the stored routine to obtain 1) a reliable and flexible data replication mechanism and 2) a faster method for querying measurement data across the SA-DDBS. In particular, the state information will always be one "hop" away from any application client. Furthermore, using consistent state information across the DBS as well as storage codes that encode measurement residuals, the SA-DDBS will provide reliable access to the archived records in an efficient way.

Results and Benefits

- **Part I – Metrics of grid vulnerability to cascading failures:**
  The project has been completed, and its results include:
  - A model of grid states as conditionally Markovian, given the process of line flows F(t).
  - A model for the line flow statistics, using measurement data on generation/loads.
  - New vulnerability measures. The metric developed is the expected active time of each line before the advent of a line trip.
  - Experiments and validation of the model proposed.
  - Software tools for vulnerability analysis and a simulation package have been developed.
- **Part II – State-aware distributed database systems:**
  Initial experiments involve the "stored procedure" to distribute state information in the DBS:
  - Decentralized state estimation via gossiping.
    - The procedure is effective for establishing the proposed P2P SA-DDBS architecture.
    - It leads to convergent estimates across the whole network with simple local communication and computations.

  The results also include the basic encoder/decoder model that utilizes the system state as side information to improve storage efficiency.
- **Technology Readiness Level:** The power grid cascading failures analysis tools we developed are ready to distribute; the other research results are in the phase of theoretical development.

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Industry Collaboration

- Worked with PNNL on Part I: Metrics of grid vulnerability to cascading failures.

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