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Deep Reinforcement Learning Applied to Grid Stability Using State Space Navigation

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Project Objective and Purpose

- During near blackout conditions, grid operators may have an opportunity to restore the system to a safe condition if a real-time decision support tool is available.
- This project investigates the development of a real-time decision support tool for that purpose.

Significance & Impact: Existing Planning and Operations

- In the infrequent occurrence when grid operations depart from planned criteria, how do we move to a ‘good’ operating point?

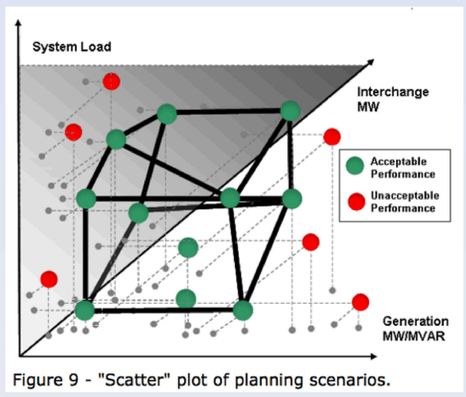


Figure 9 - "Scatter" plot of planning scenarios.

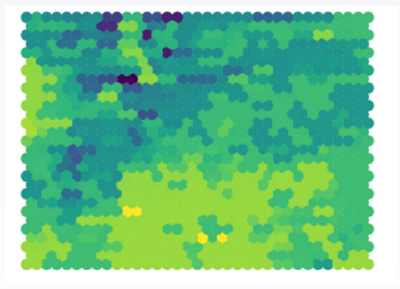
- Where are we? Where do we want to go? What path do we take?

Significance & Impact: Metaphor For Stability Margin

Require “Stability” Margins of Interest

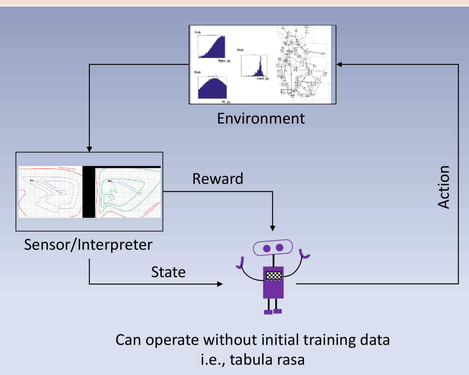
- Voltage Stability Margin
- Transient Stability Margin
- Non-Linear/Eigen-analysis Stability Margin
- System Voltage Margins
- Power Line Transfer Margins
- System Droop Margin

Technical Approach: State Space Visualization



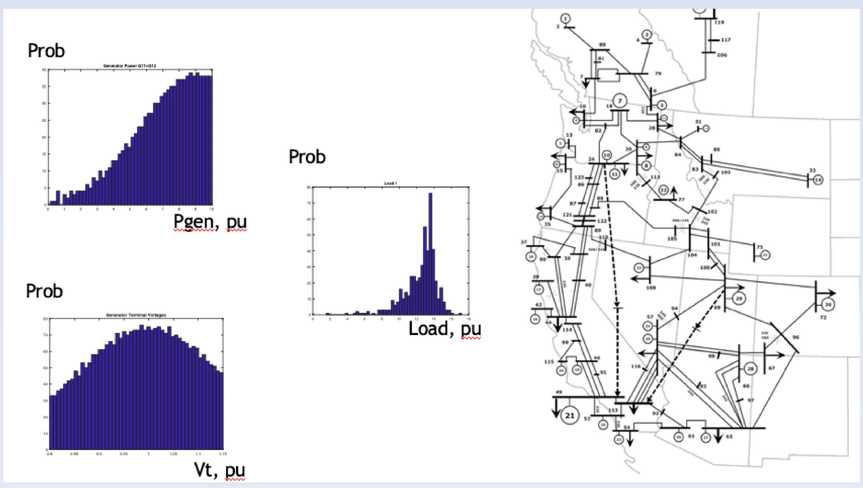
15-dimensional grid state data (1,001 precomputed points) flattened onto a 2D hex. Light yellow represents high stability scores, dark blue represents low stability. The plot shows spatial correlation and bounded stability regions, validating a machine learning approach!

Technical Approach: Reinforcement Learning

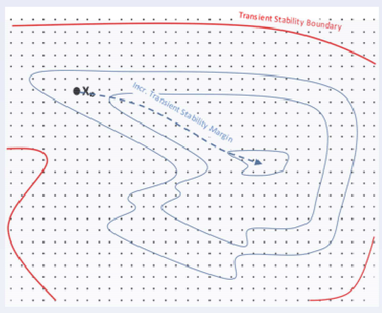


Can operate without initial training data
i.e., tabula rasa

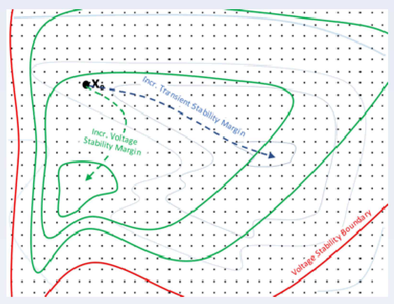
Technical Approach: Defining the State Space



Technical Approach: Stability Margins



Transient Stability Level Curves



Transient Stability and Voltage Stability Level Curves

Technical Approach: AlphaGrid Game

Game objective

- Increase score by moving from the current state to a state with high stability margins
  - In the fewest moves possible
  - While maintaining high stability margins during all state changes

Game setup

- Game board is the grid state space and associated stability margin penalties
- Initial state is a marginally stable grid condition

Rules for discrete state transitions

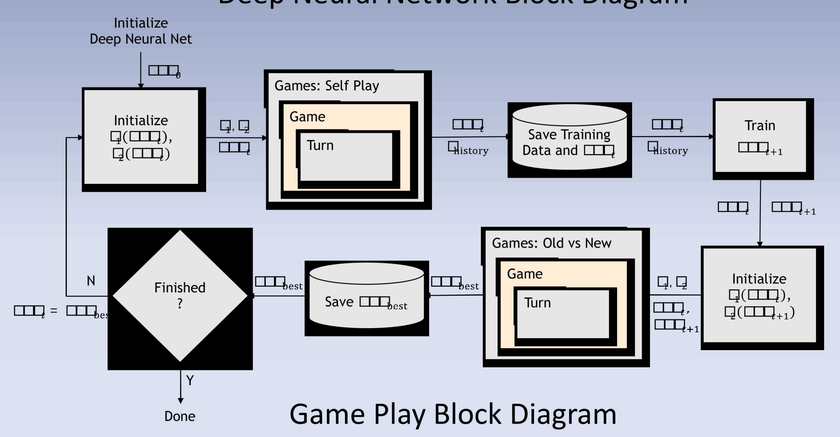
- Each state transition is bounded to nearby neighbors
- Journey to the final state is performed using a sequence of state transitions
- States are not allowed to be re-visited
- Cannot transition to unstable state
- State transitions are
- Selected from the combined DNN and MCTS during game play
- Learned during training in the DNN

Reinforcement Learning Also Applies to:

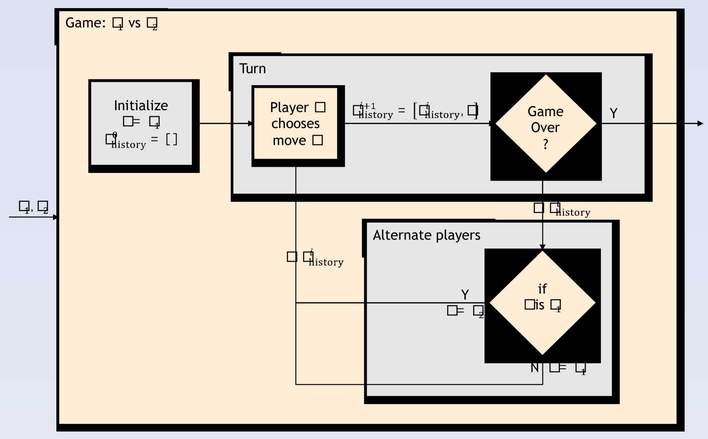
- Cyber security
- Physical security
- Counter autonomy (drones
- Space resilience)

Technical Approach: AlphaGrid

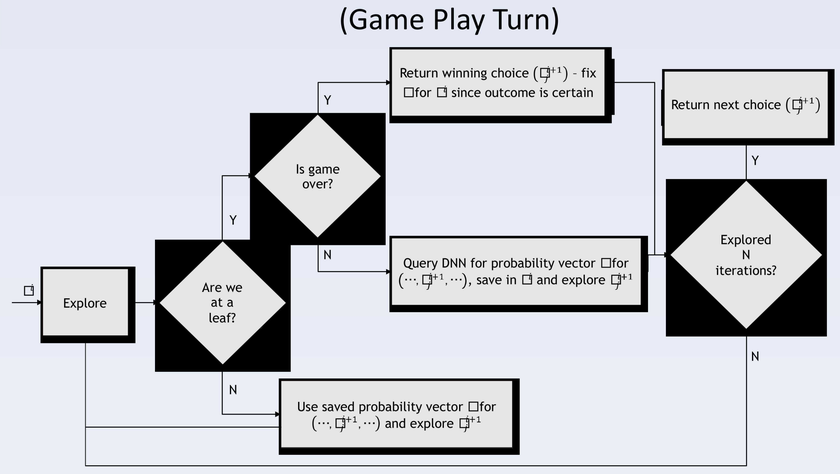
Deep Neural Network Block Diagram



Game Play Block Diagram



Monte Carlo Tree Search (MCTS) Block Diagram (Game Play Turn)



Technical Approach: AlphaGrid Game

Scoring includes

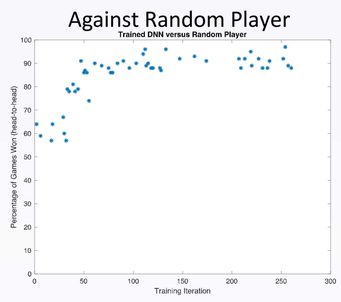
- Aggregate state change stability margin penalty
- Penalties for more transitions
- Improves for a transition to a more stable state
- Degrades for a transition to a less stable state

End of the game is reached when

- Maximum number of transitions is exhausted
- No possible transition to stable states exists

Preliminary Results

Against Random Player



Reports and Publications

1. Guttromson, R., Verzi, S., Dawson, L., Levin, D., Melander, D., Sorensen, A., Cauthen, K., Wilches-Bernal, F., Berg, T., and Lavrova, O. (2018). “Integrated Cyber/Physical Grid Resiliency Modeling”. Sandia Report, SAND2018-876234.

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