Policy-Switching Schemes for Power System Protection

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Motivation for Automated Contingency Mitigation

1. Continued widespread outages that require effective cascading restraint.
2. Non-uniform implementation of remedial action schemes (RASs) (SPSs).
3. Increased variability in generation (renewables).
4. Greater network congestion.
5. Malicious attacks (cyber or physical).
6. Higher penetration of distributed energy resources (DERs) (energy storage & small-scale distributed generation).

Load Shedding (LS)

CHARACTERISTICS

- Naive and Homogenous:
  - Affects all loads in the network.
  - Usually triggered by under-voltage conditions.
- Adaptive and Dynamic:
  - Ability to select loads based on a rule. (priority, severity, electrical distance, etc.)
  - Usually triggered by multiple conditions (UV, UF, $\frac{dV}{dt}$, $\frac{dF}{dt}$).

LS BENEFITS

- Direct manipulation of generation/load mismatch.
- Can be done in real-time.

LS CHALLENGES

- Direct customer impact.
- Must be done incrementally.

Islanding

CHARACTERISTICS

- Intentional creation of microgrids.
- Typically pre-determined based on common contingencies.
- Usually done based on slow-coherency, electrical distance, active/reactive power balance.

BENEFITS

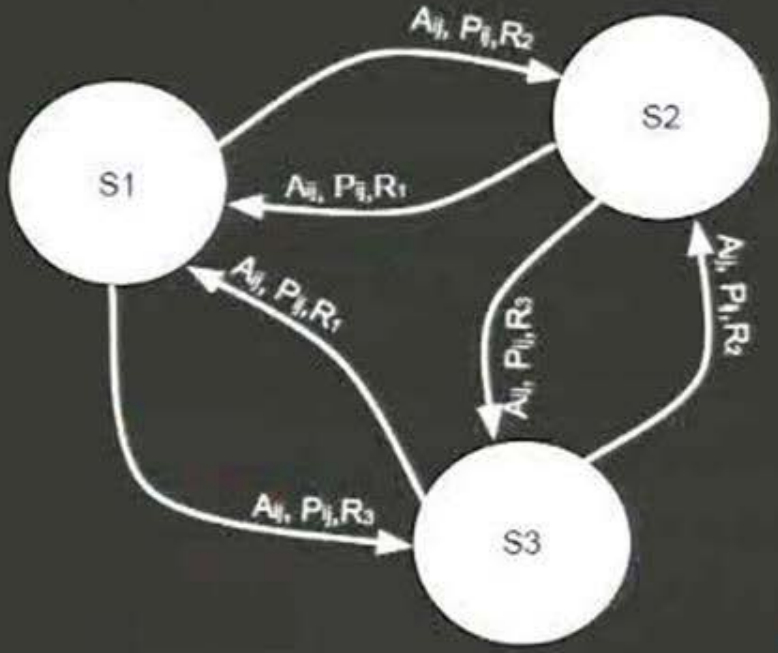
- Can isolate operational sections from affected sections.
- Can fully utilize DER capability to decrease impact on customers.

CHALLENGES

- Slow calculation – usually done offline.
- Can cause portions of the grid to fully collapse.

Markov Decision Processes (MDP)

MDPs provide well-developed theory for computational solutions to controllable and observable systems with stochastic dynamics.



MDP COMPONENTS

- System States (S): Time Independent
- Control Actions (A): Stationary or Non-Stationary
- Probabilistic Transition Distributions (P): Stochastic Movement Between States
- Rewards (R): Function of Current State

Solutions to MDPs

What is the solution to an MDP?

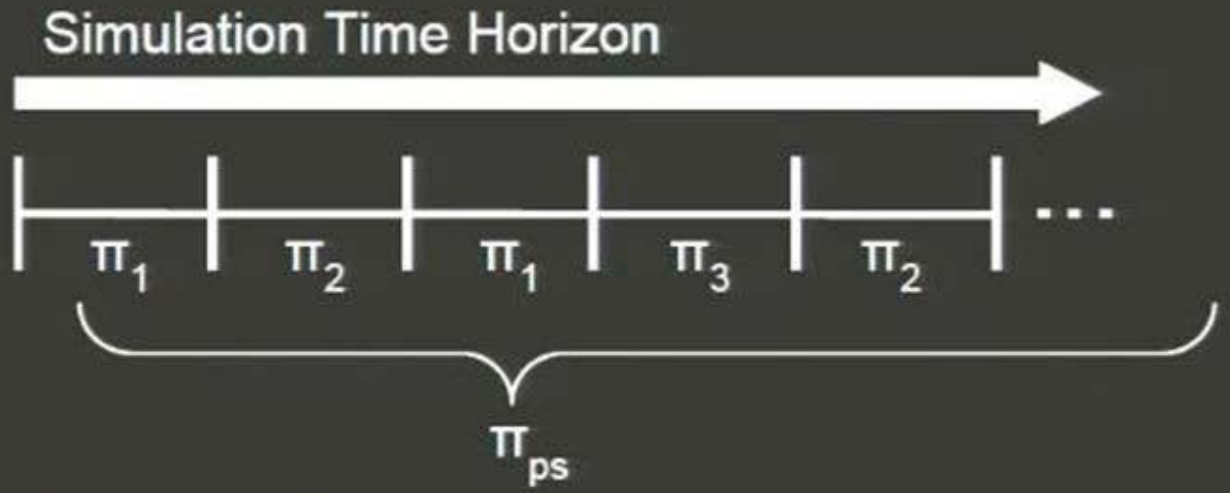
Policy (π) = A mapping of States (s) to Actions (a).

Optimal Policy (π^*) = Policy with max *Value* (V) in any given state (s).

Value:

$$V^{\pi}(s) = E\left[\sum_{t=0}^{\infty} \beta^t R(s_t)\right]$$

Policy Switching



Formally:

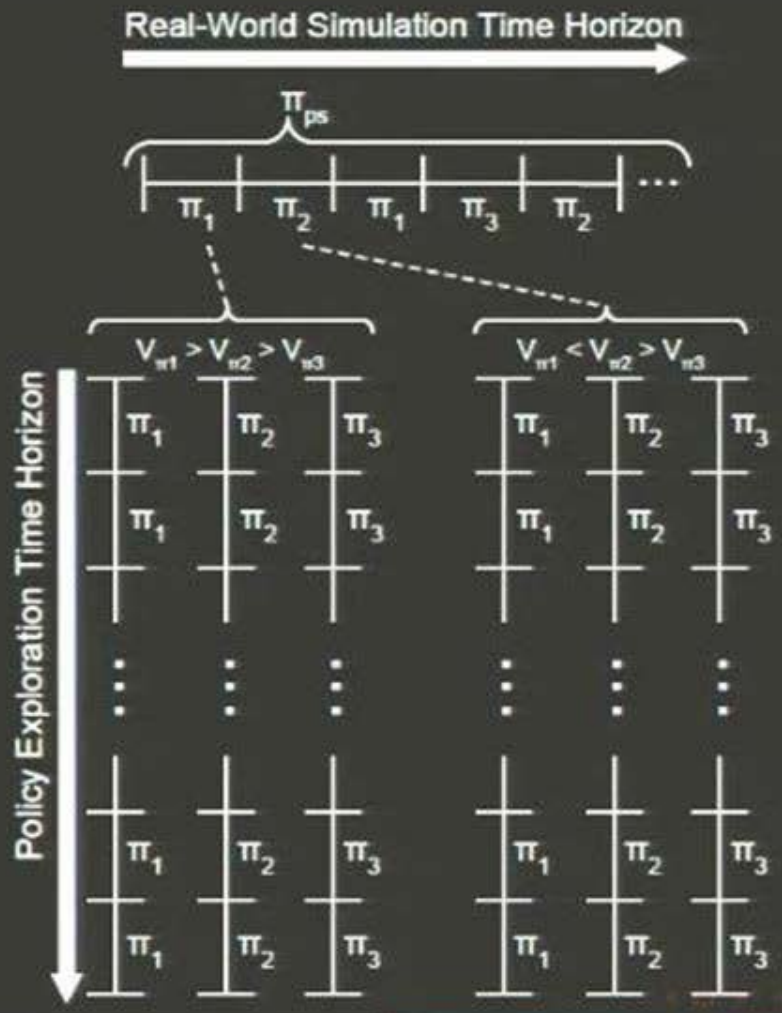
$$\pi_{ps}(s) = \pi_{i^*}(s)$$

$$i^* = \arg\max_i V_{\pi_i}(s)$$

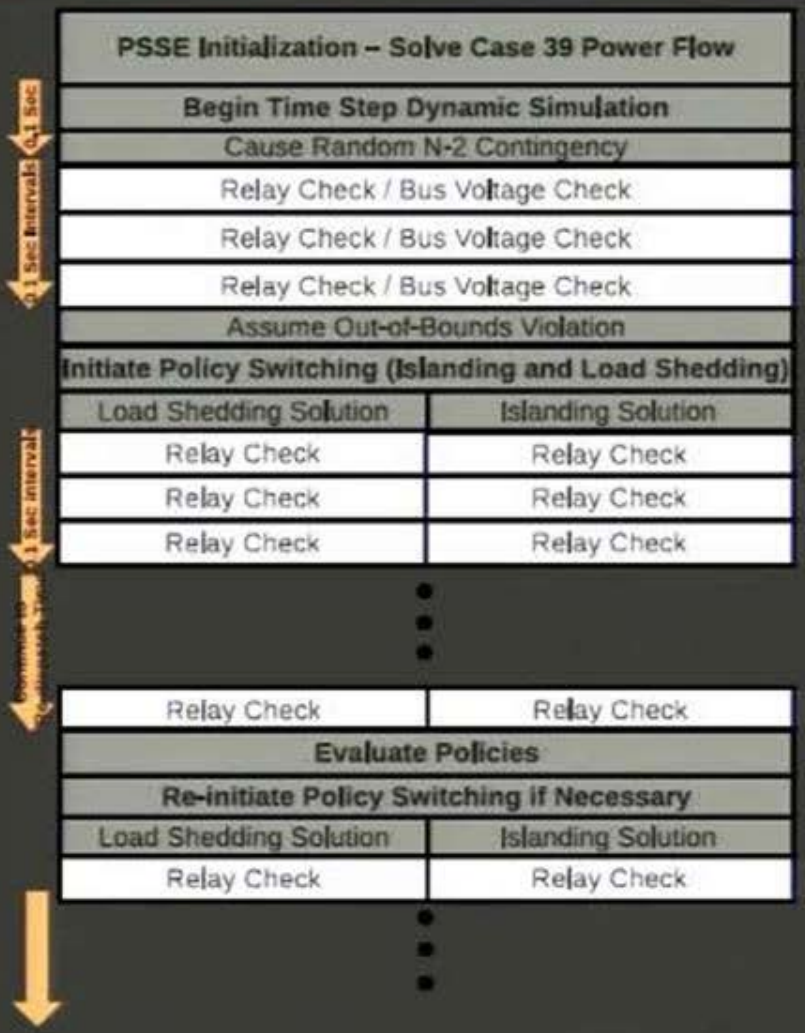
Policy Switching:

Basic guarantee that
$V(\pi_{ps}) \geq \max_i V(\pi_i)$

Policy Switching

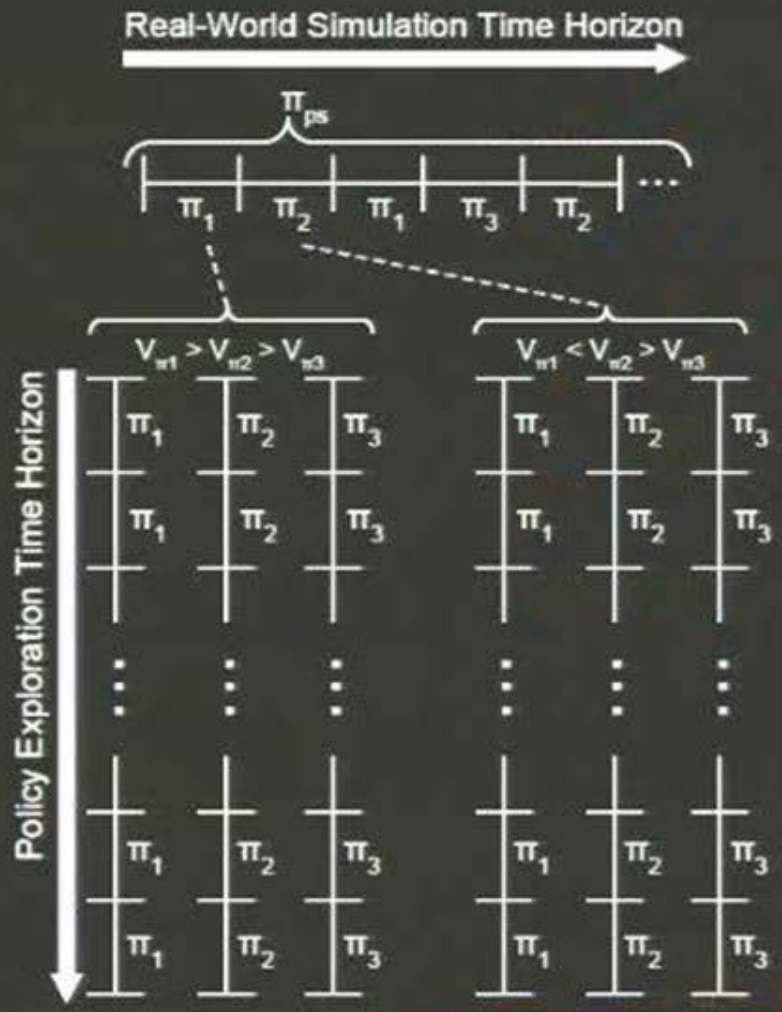


Implementation



1. Python/Siemens PSSe
2. Time-Domain Simulation
3. 3 Different Timescales
   1. $\frac{1}{120}$ s – PSSe step
   2. $\frac{1}{10}$ s – Grid check
   3. 5 s – Emgcy. dispatch
4. Random N-2 Contingencies
5. Parallelization

Policy Switching



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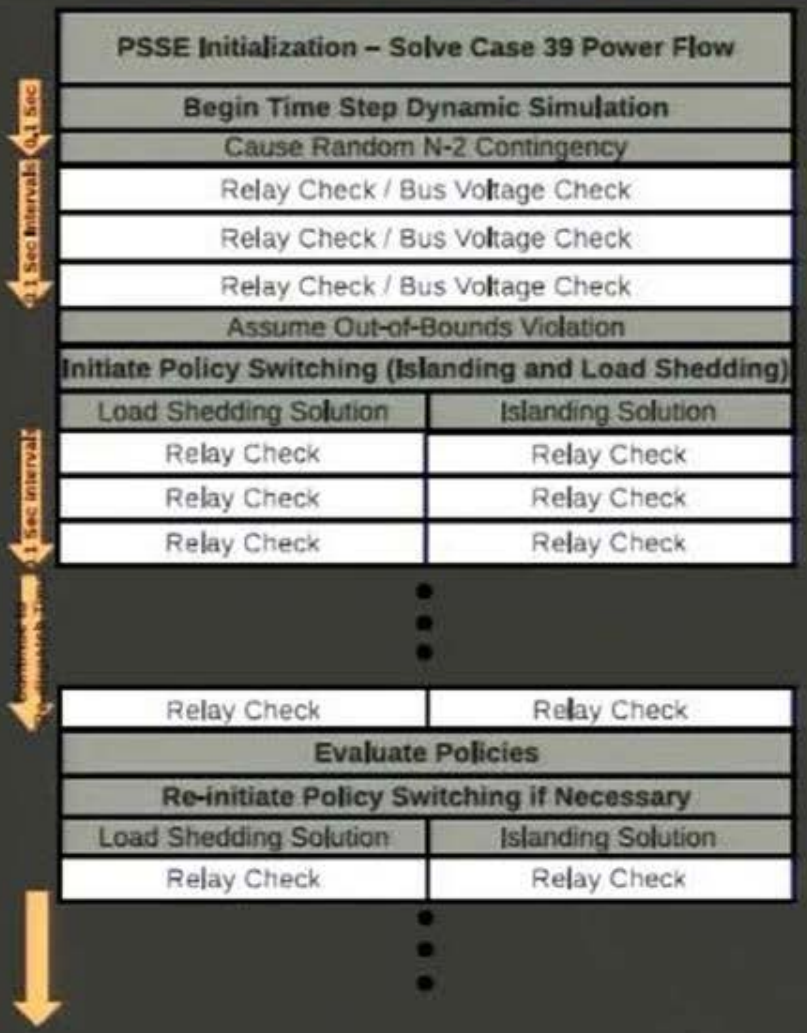

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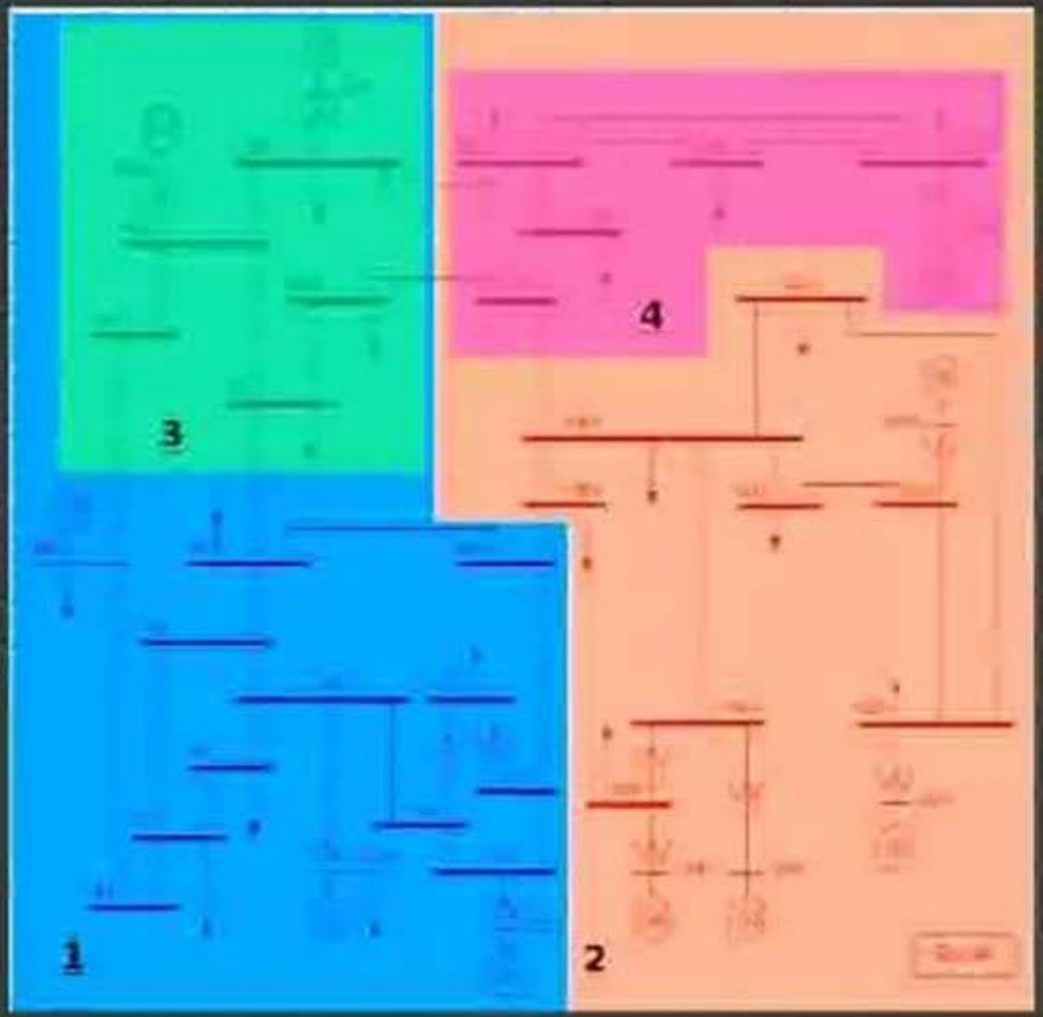
Test Case Overview



- Case Topology
  - 39 Buses
  - 10 Generators
  - 19 Loads
  - 46 Branches
- N-1 Secure
  - Flow Limits
  - Governor Dynamics
  - Exciter Dynamics

Case Study [19-20 and 2-25]

Policy Available (Π):	Islanding (I)	Load Shedding (LS)	Islanding and Load Shedding					
FIRST POLICY	I	LS	I	I	I	LS	LS	LS
Operational Load (L) [MVA]	4759	5224	4759	4759	4759	5224	5224	5224
System Saved (B)	NO	NO	NO	NO	NO	NO	NO	NO
Reward* (V^{**})	0.366	0.401	0.366	0.366	0.366	0.401	0.401	0.401
# Buses Lost	7	3	7	7	7	3	3	3
# Generators Lost	2	2	2	2	2	2	2	2
# Full Loads Lost	4	1	[illegible]	5	4	1	1	1
# Transmission Lines Lost	13	5	13	13	13	6	6	6
SECOND POLICY	I	LS	I	LS	LS	LS	I	I
Operational Load (L) [MVA]	3848	2922	3848	4283	4283	2922	4749	4749
System Saved (B)	NO	YES	NO	YES	YES	YES	YES	YES
Reward* (V^{**})	0.296	0.725	0.296	0.829	0.829	0.725	0.865	0.865
# Buses Lost	14	21	14	7	7	21	5	5
# Generators Lost	3	5	3	2	2	5	2	2
# Full Loads Lost	8	9	8	4	4	9	3	3
# Transmission Lines Lost	21	27	21	13	13	27	9	9
THIRD POLICY	I*	LS**	LS	I**	LS**	I**	LS**	I**
Operational Load (L) [MVA]	-	-	5483	-	-	-	-	-
System Saved (B)	-	-	YES	-	-	-	-	-
Reward* (V^{**})	-	-	0.766	-	-	-	-	-
# Buses Lost	-	-	14	-	-	-	-	-
# Generators Lost	-	-	3	-	-	-	-	-
# Full Loads Lost	-	-	8	-	-	-	-	-
# Transmission Lines Lost	-	-	21	-	-	-	-	-

[illegible] [MVA]

*No [illegible] islanding policy available [illegible]

**Not needed [illegible]

Key Takeaways

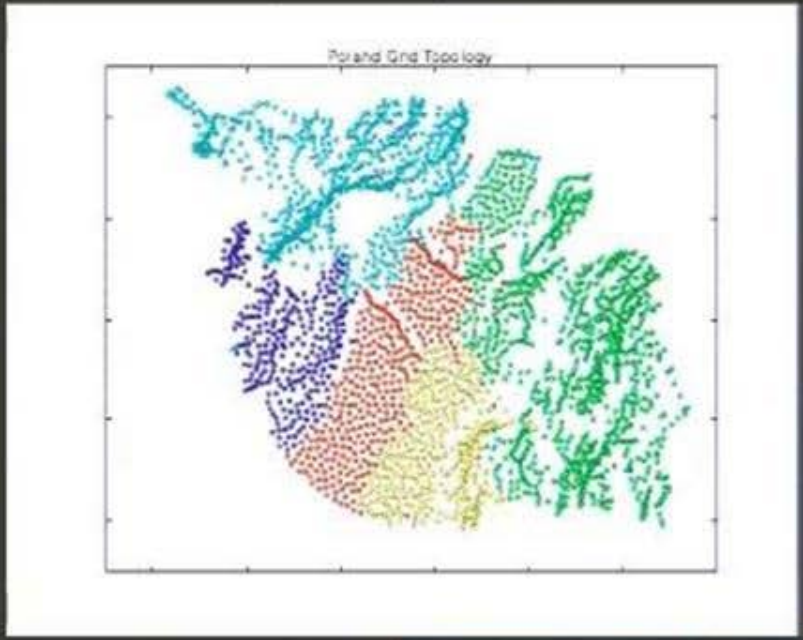
- Introduced Policy Switching in the context of Power Systems.
- Quantitative analysis of our methodology – case study on IEEE-39.
- Basic enumeration of each policy's performance.

VALUE FUNCTIONS RESULTS

Experiment	Policies Available (Π)	$V^{\pi}(s)$	Operational Load [MVA]
1	I	0.296	3848
2	LS	0.725	2922
3	I & LS	0.865	4749

Current Work

- Implement on larger grid and with several policies in order to assess scalability.
  - Polish Grid (2383 Bus Winter Peak Model).
  - Improve automation of policy evaluation.
  - Scalability and computation time on different resources: computer, server, supercomputer, etc.



Moving Forward

- Expand Action-space.
- Test with different percentages of variable renewable generation.
- Re-evaluate Reward Scheme
- Compare Results using different simulators.
- Compare Results against various AI schemes.

THANK YOU

QUESTIONS?

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