Testing and Demonstrating

a Stigmergic Control Strategy

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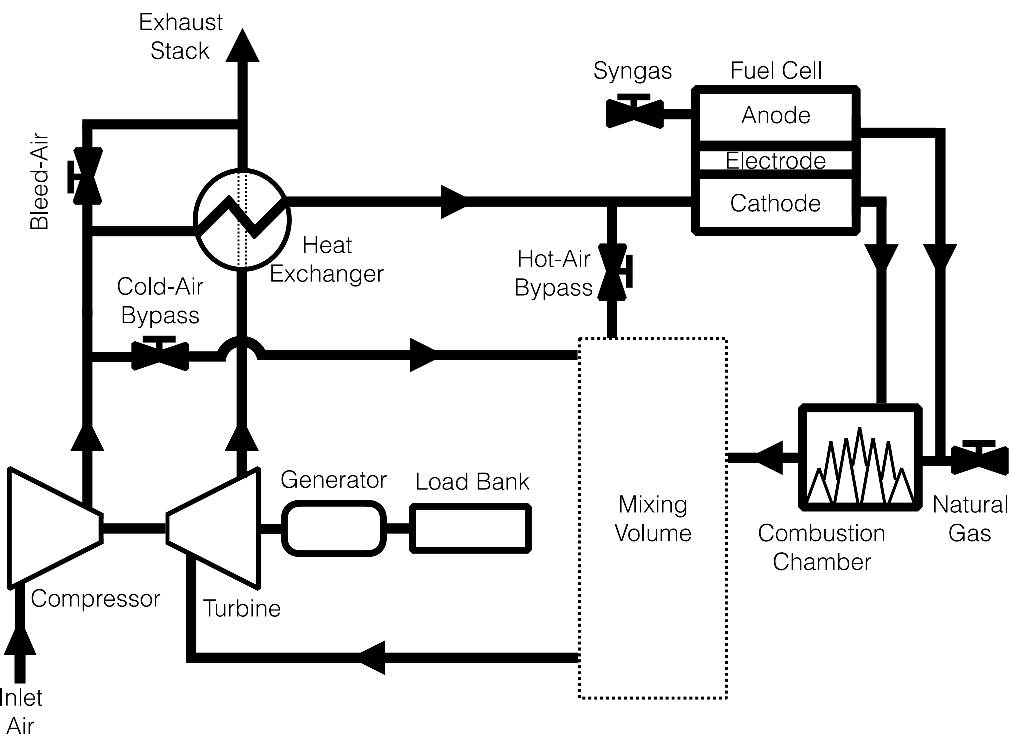
Simulation, Modeling, & Decision Science


Increasing energy use
Increasing impact on the environment
Increasing resource scarcity

Hybrid systems

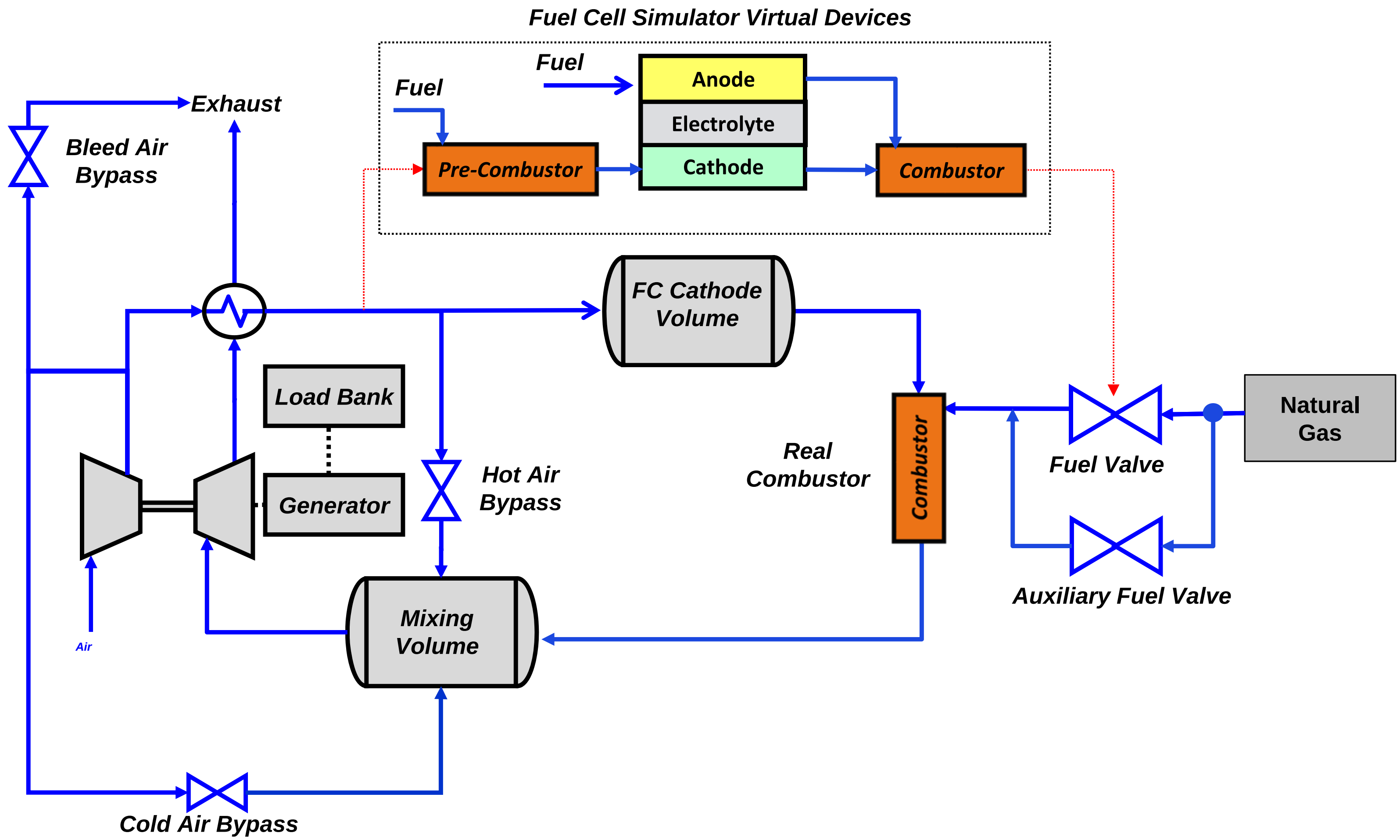
- High efficiency
- Low emissions



Innovative control solutions

- Coupling between energy devices
- Different time scale
- Increase turn down flexibility
- Adaptability, scalability and reconfigurability

Advanced hybrid systems



Hyper configuration

1. Multivariable control strategy

2. Multi-agents control solutions (Stigmergic)

State Space System Modeling

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Input

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \\ b_{31} & b_{32} \\ b_{41} & b_{42} \end{bmatrix} \cdot \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

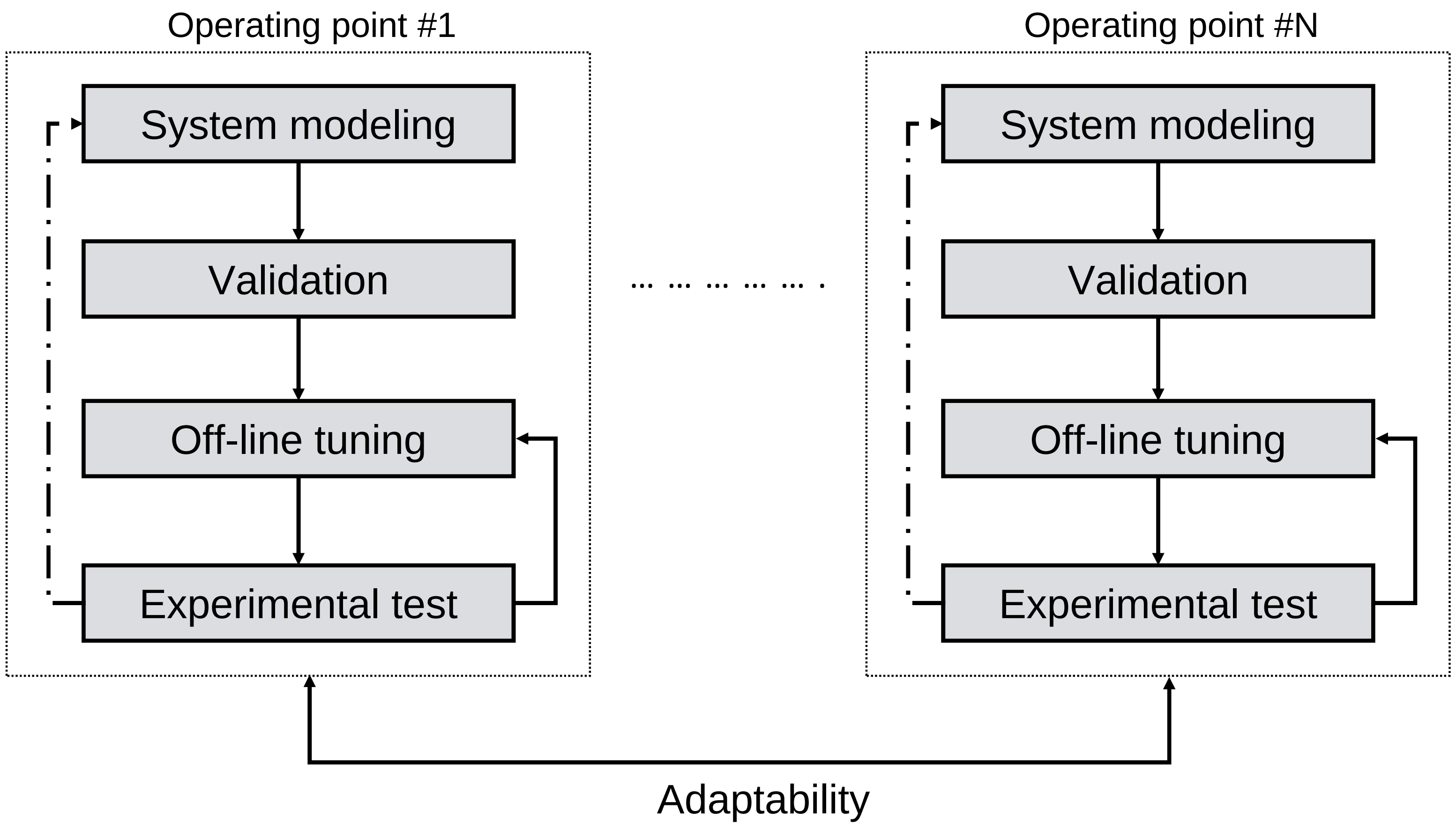
$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

y

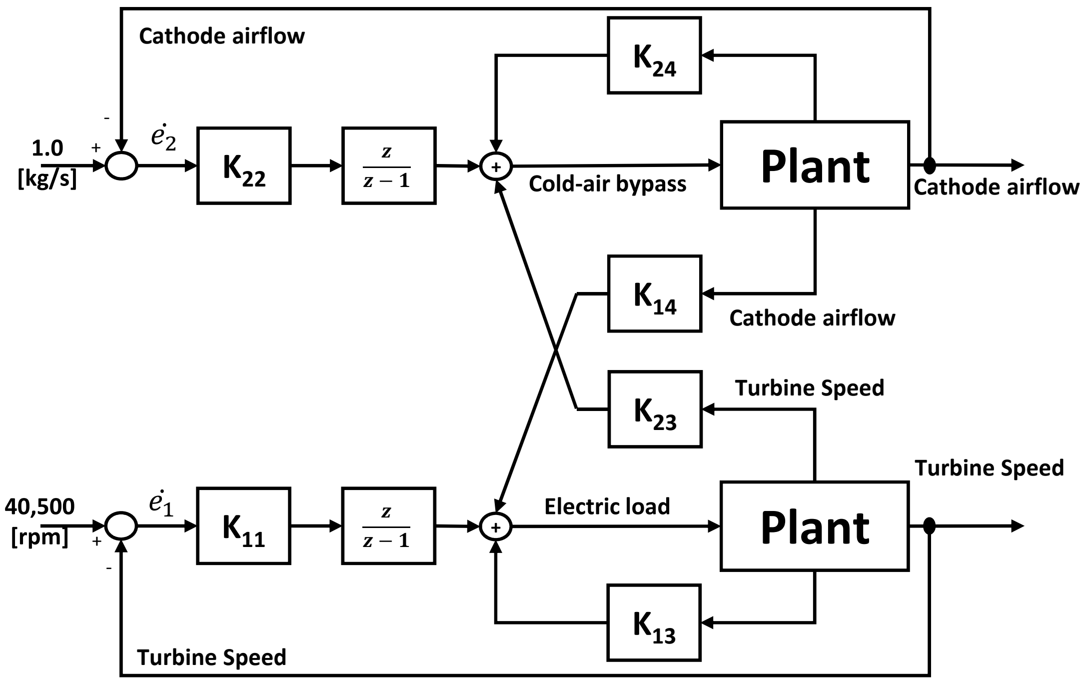
Output

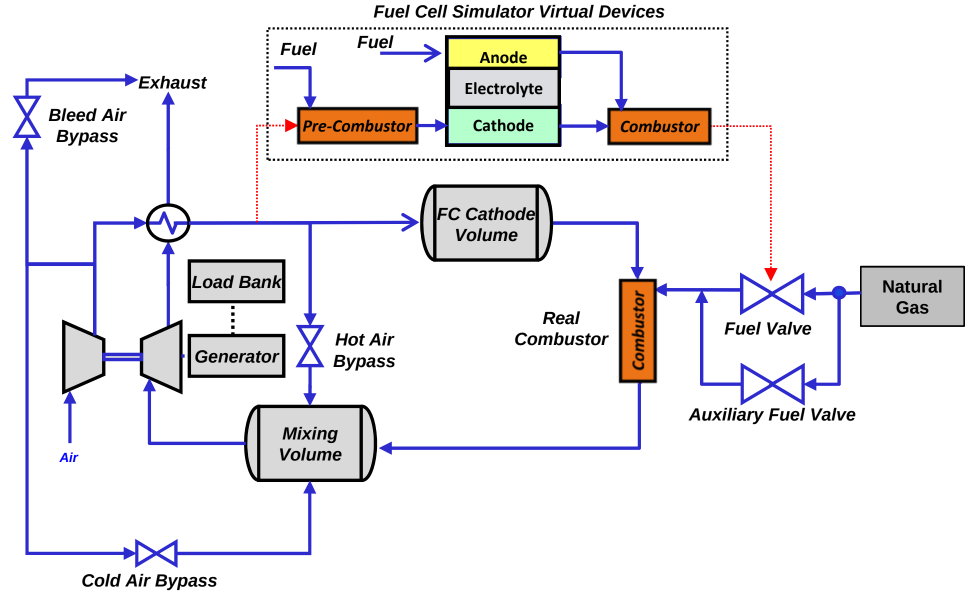
High Complexity in

- System Modeling
- Tuning
- Adaptability

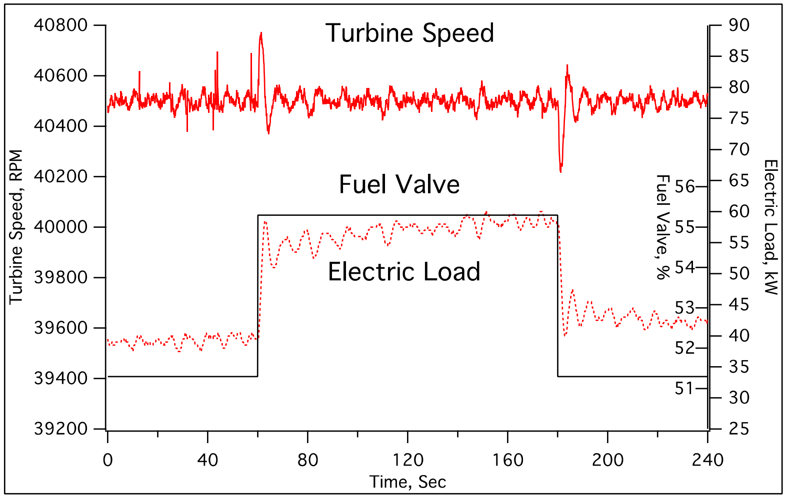


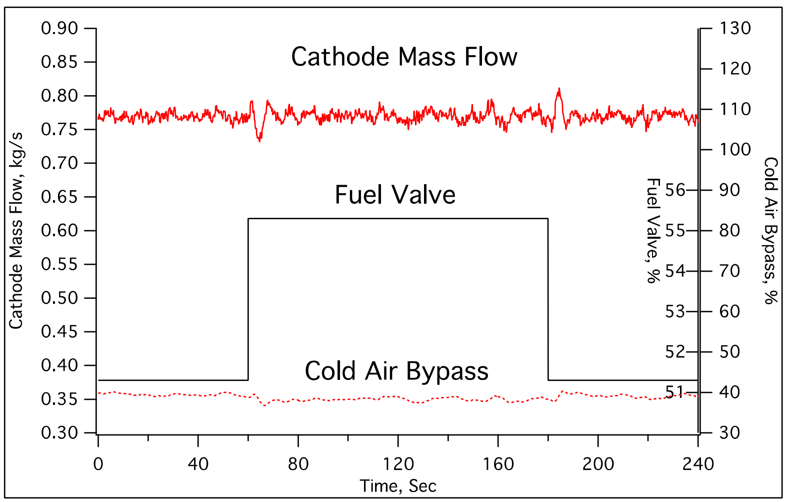
Multivariable Control Procedure





Mitigation of Decentralized Interactions





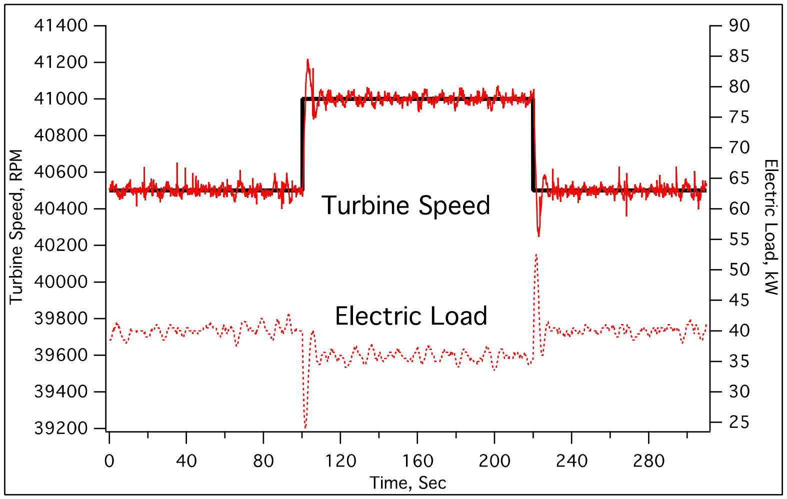
Fuel valve perturbation (4%):

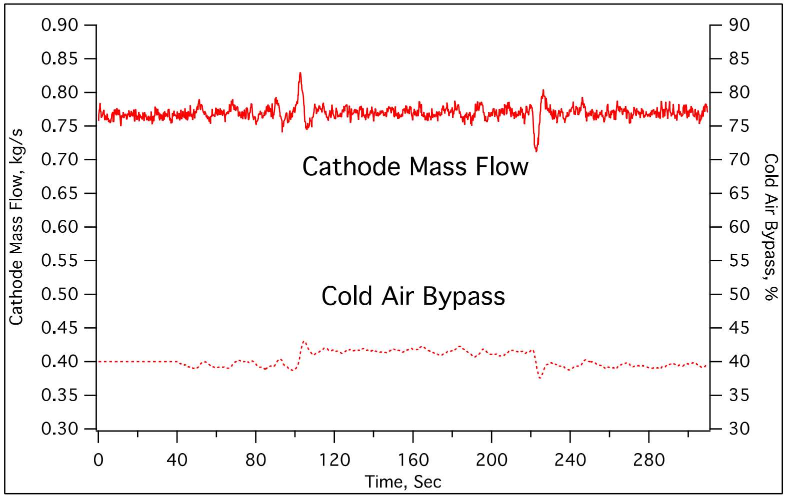
- 4% = 200 kW_{th}
- 200 kW_{th} = 35 kW_{el} in the fuel cell
- 35 kW_{el} = 10% load turn down

Deviation at nominal conditions

- Turbine speed = 300 rpm
- Cathode airflow = 0.03 kg/s

Multivariable Results – Disturbance Rejection





Turbine Speed Perturbation

- 500 rpm
- 1.2% of the full range operation

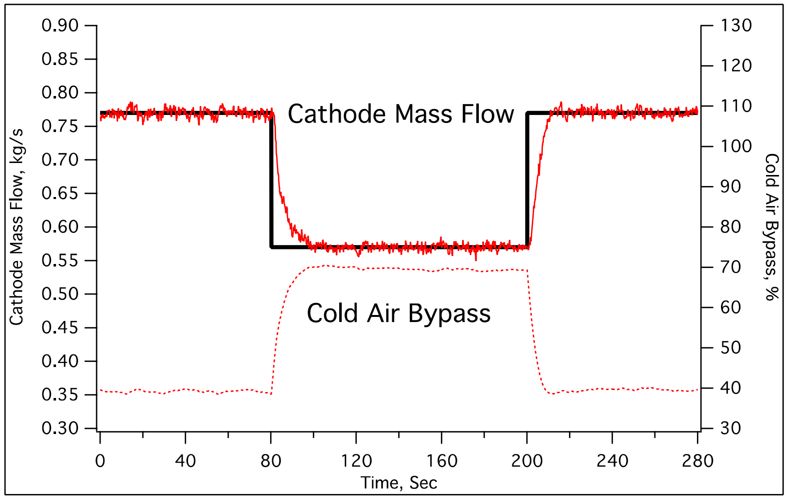
Deviation at nominal conditions

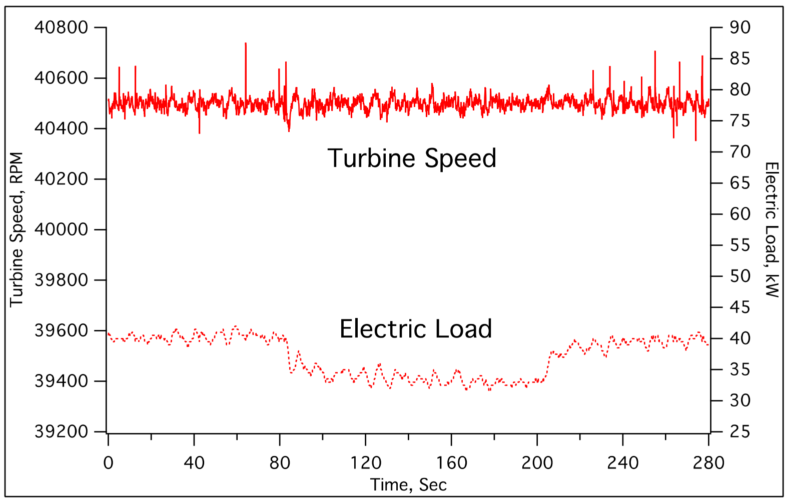
- Overshooting = 200 rpm (40%)
- Cathode airflow = 0.05 kg/s

Maximum rate of change

- Electric load = 18.75 kW (80 ms)
- Cold-air bypass = 1.79% (80 ms)

Multivariable Results – Set-point Tracking





Cathode airflow Perturbation

- 0.2 kg/s
- 20% of the full range operation
- 1,000 rpm of coupling rejected

Maximum rate of change

- Electric load = 6.25 kW (80 ms)
- Cold-air bypass = 6.21% (80 ms)

Multivariable Results – Set-point Tracking

Construction behavior from social insects

Insects accomplish tasks without centralized authority

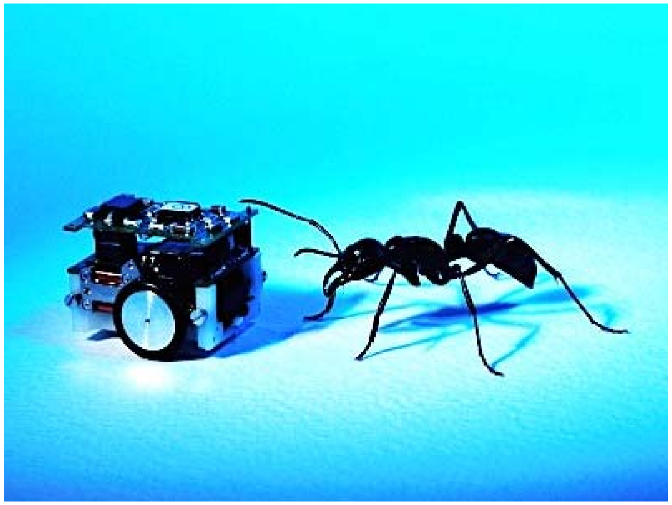
Modifications to the environment are used to communicate and coordinate actions

Distributed construction - Stigmergic

Computational agents represent insects

Agents imitates the construction behavior of social insects

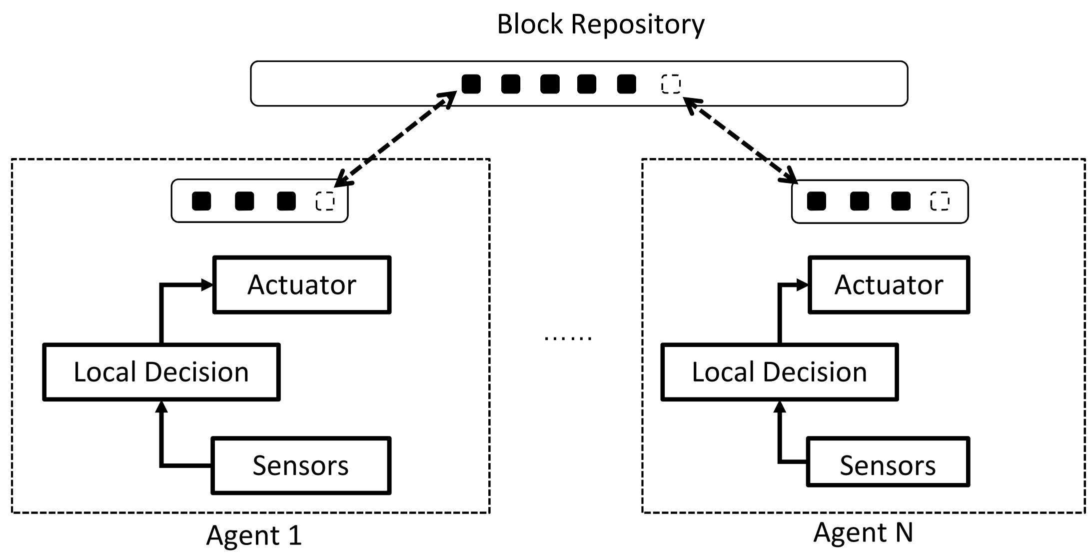
Each agent takes independent decisions



Stigmergic

Flexibility
Agent can easily be added or taken away

Adaptability
Overcome changes in the environment



Grouping sensors and actuators in computational agents

Shared Resource (Blocks)

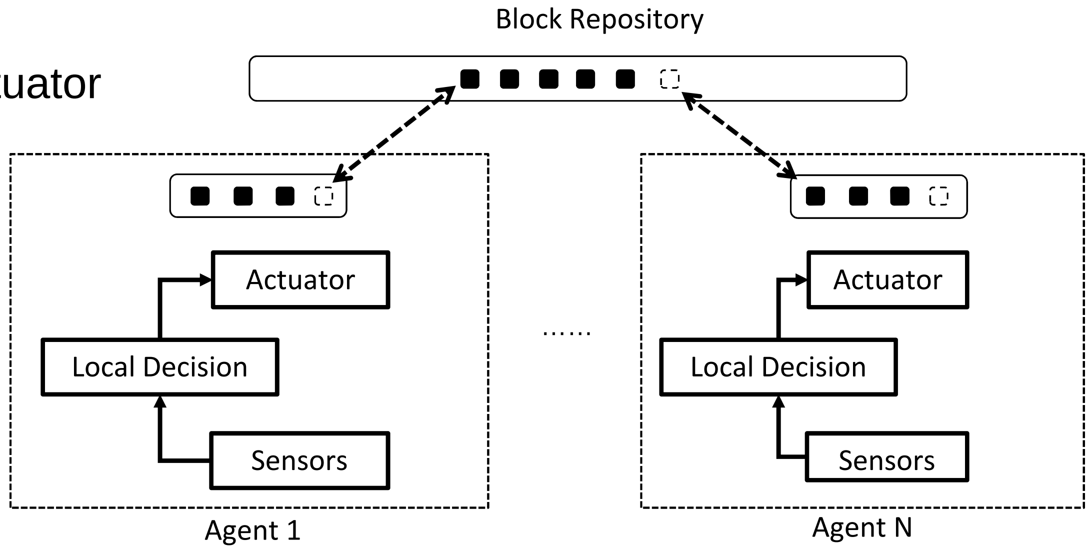
- Establishes cooperation and sharing
- Blocks are a discrete unit of change to an actuator

Random Number Generation

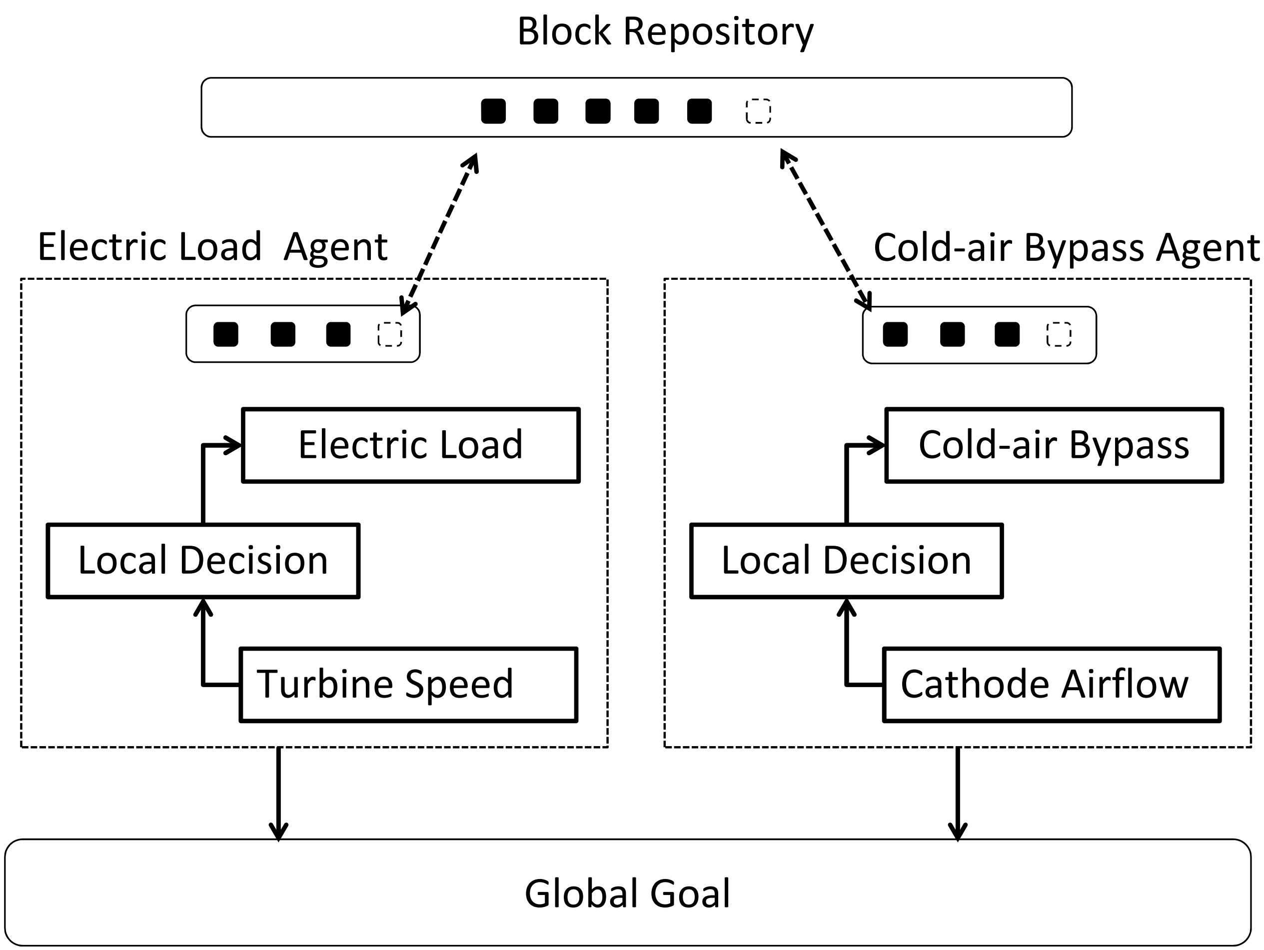
- Emergent behavior found in social insects
- An agent is selected randomly

Probability of action

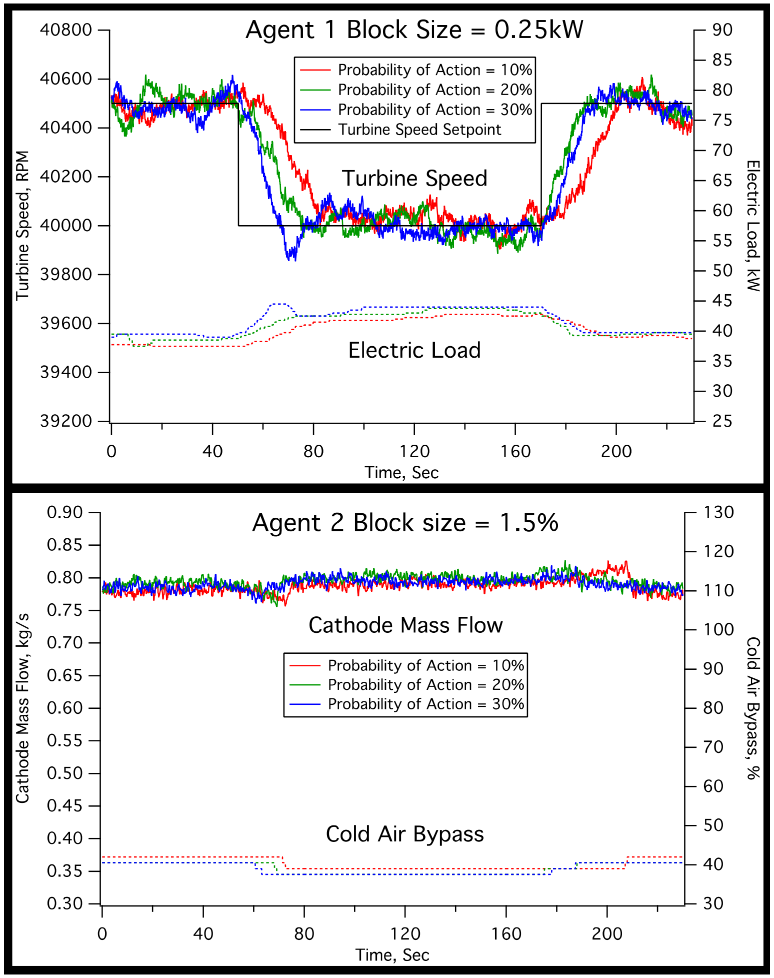
- Determines frequency of action taken

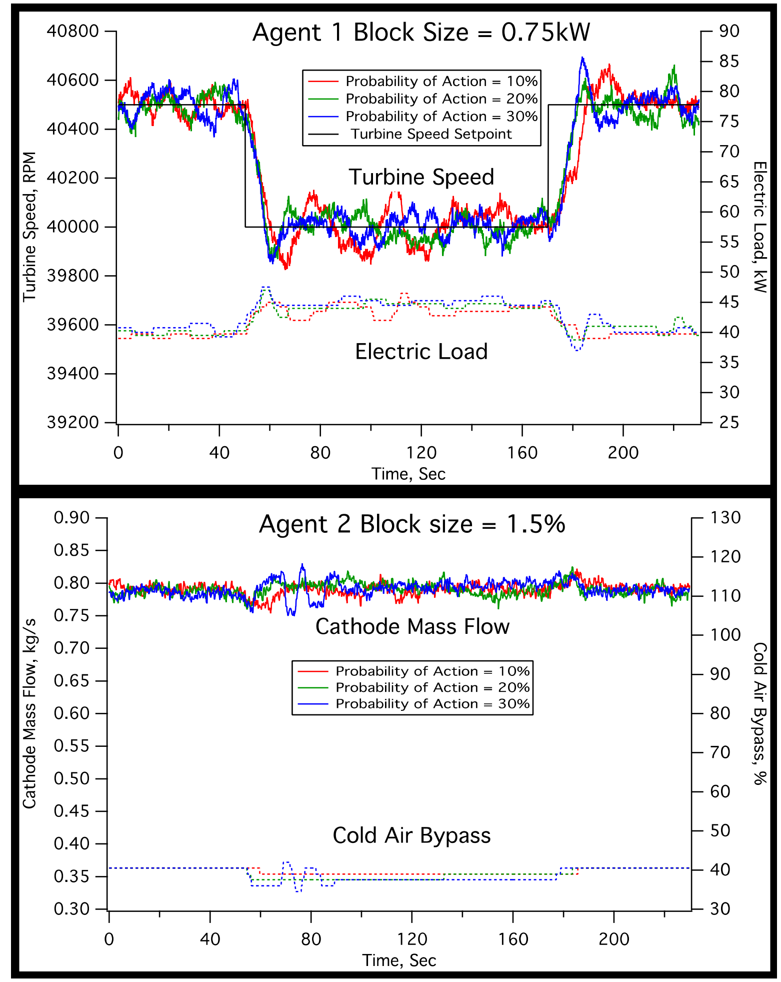


Resource sharing algorithm

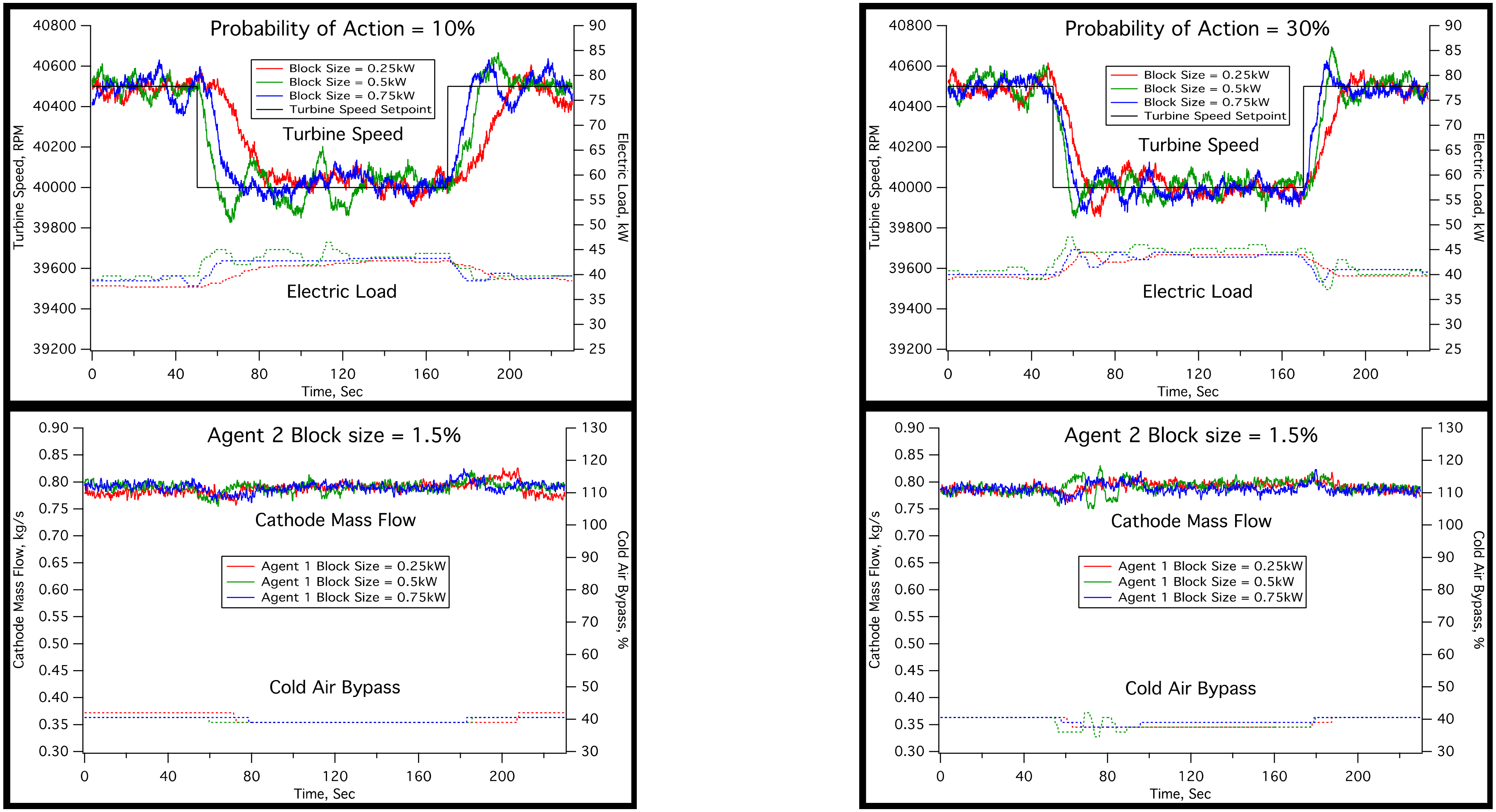


Stigmergic Control Schema

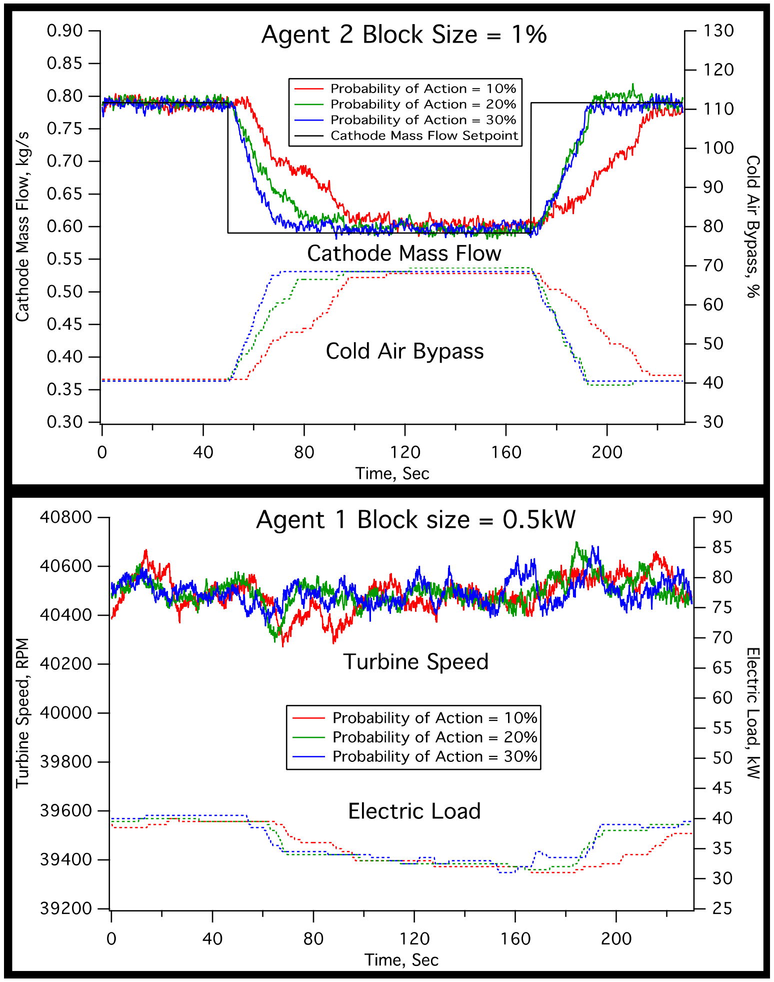


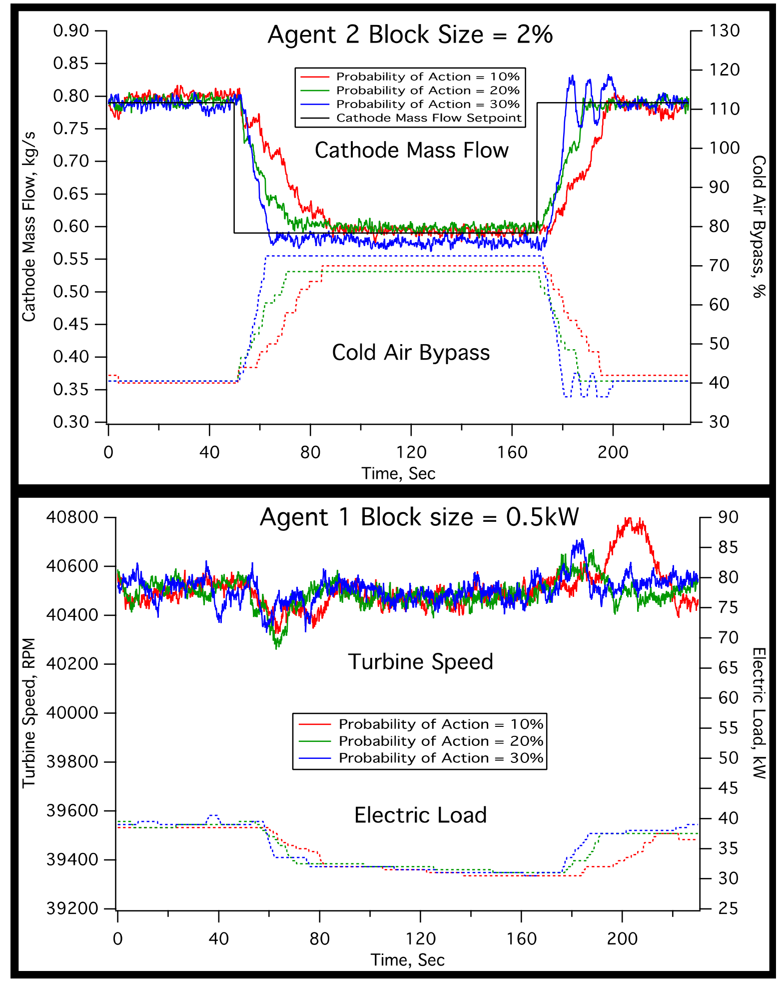


Stigmergic Results – Agent 1 Block Size

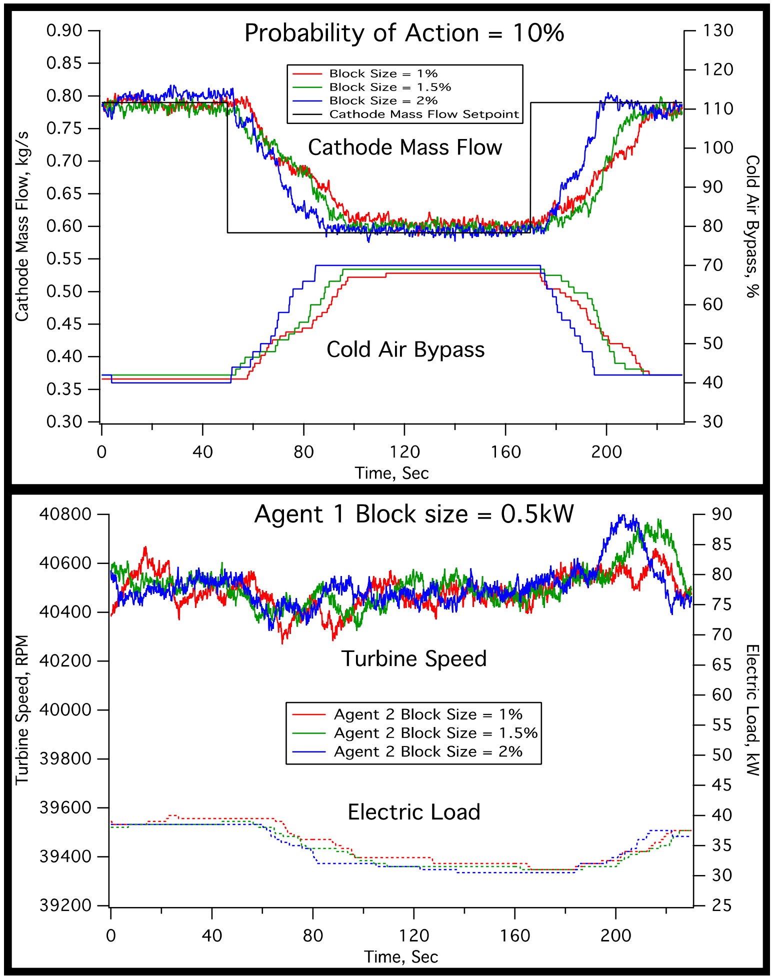


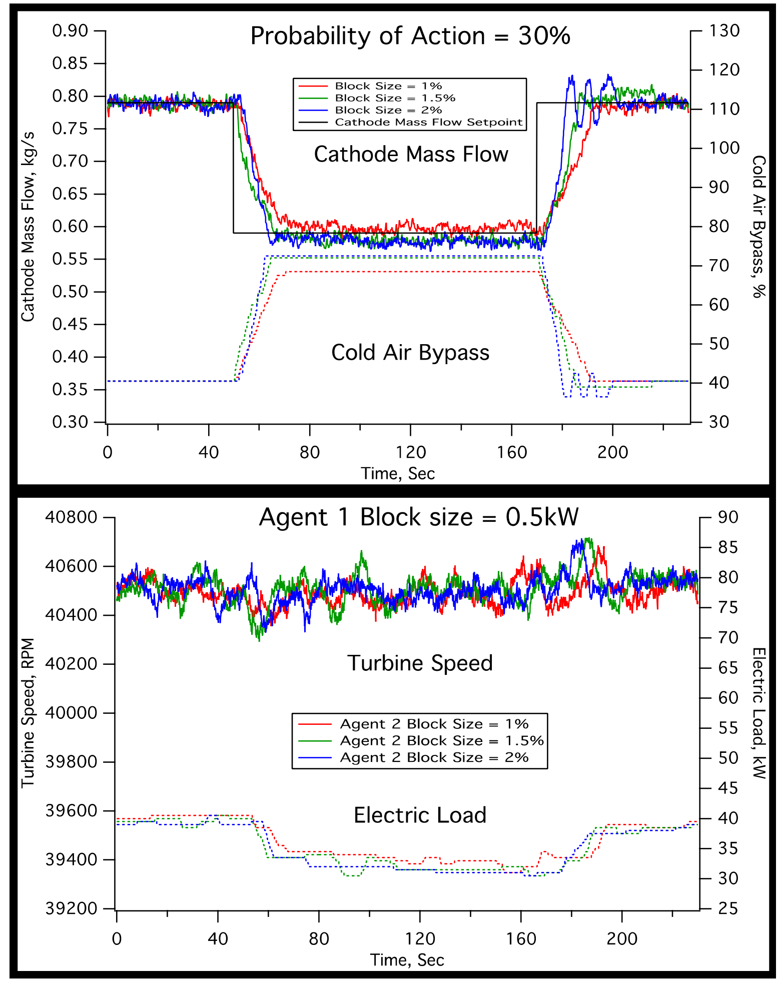
Stigmergic Results – Agent 1 Probability of Action



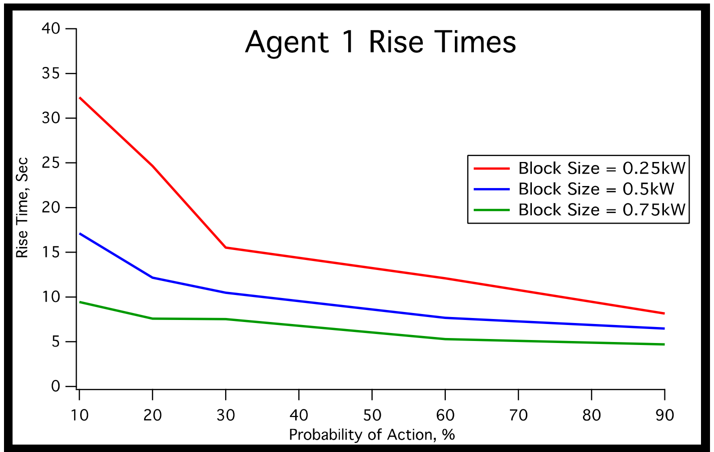


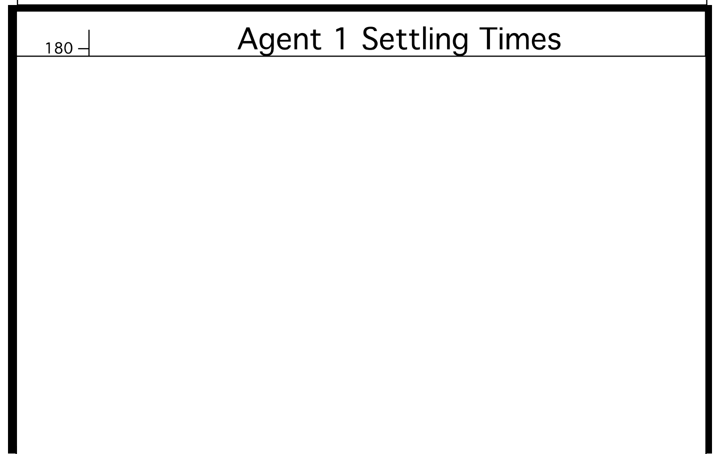
Stigmergic Results – Agent 2 Block Size

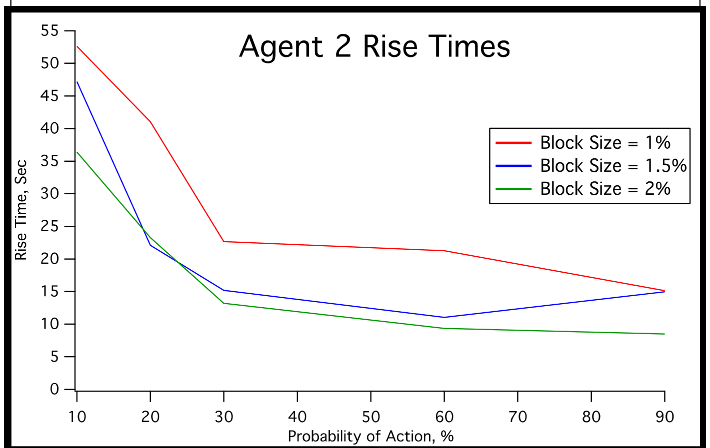


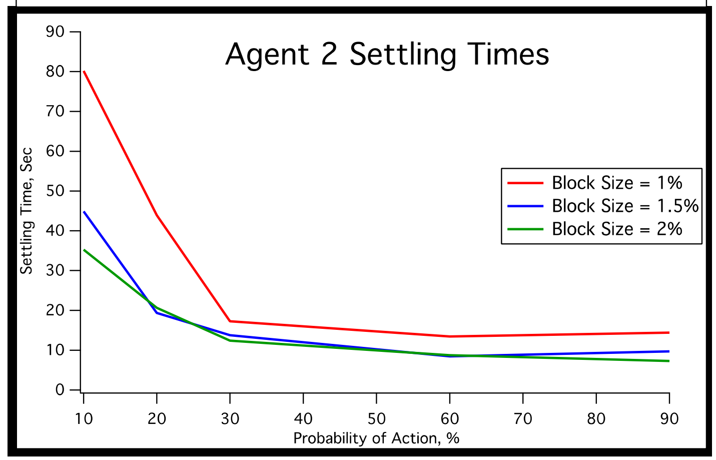


Stigmergic Results – Agent 2 Probability of Action



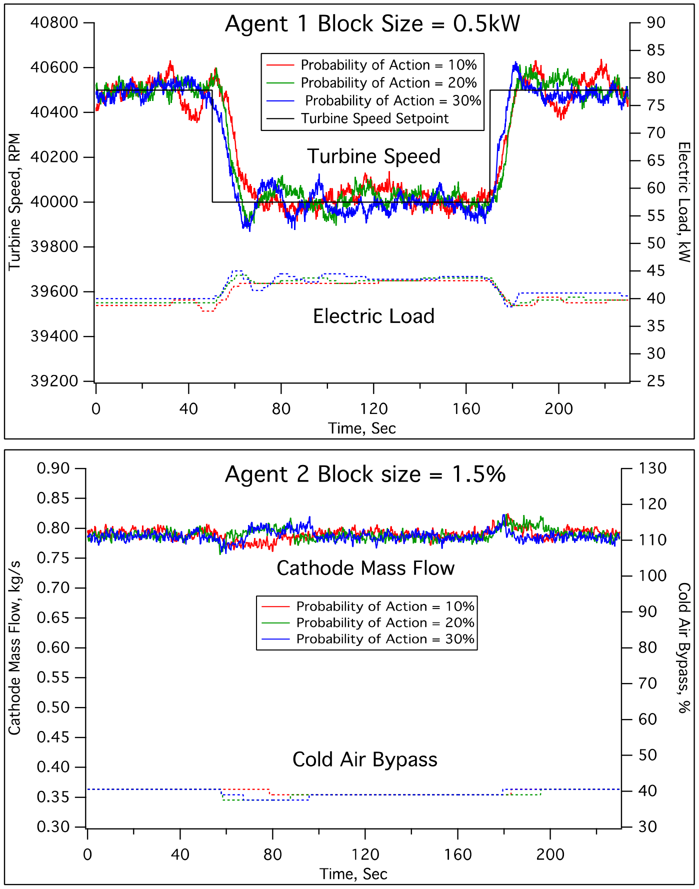




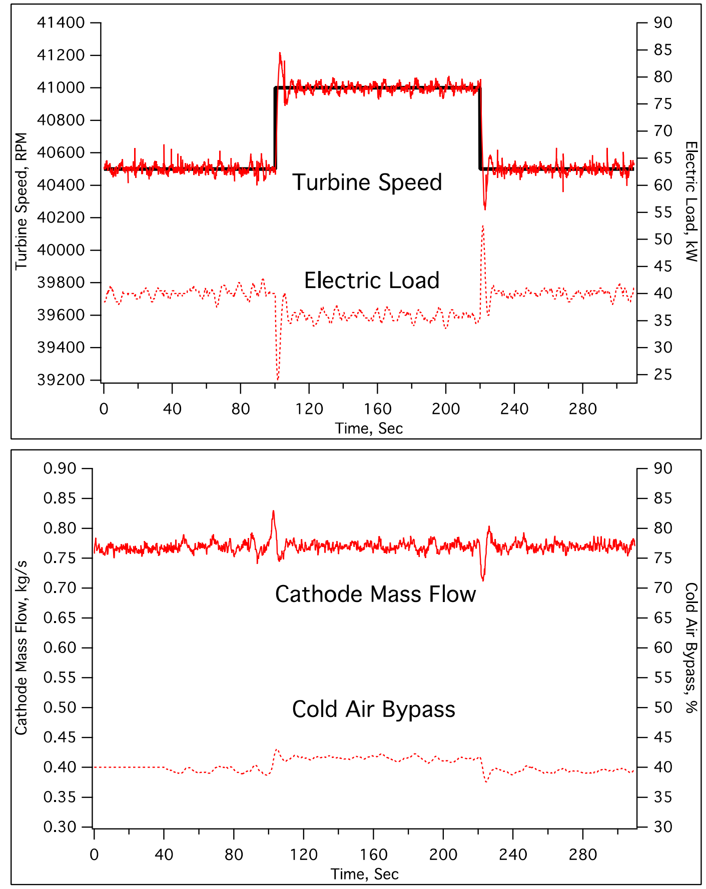


g Parameter Results

Stigmergic response

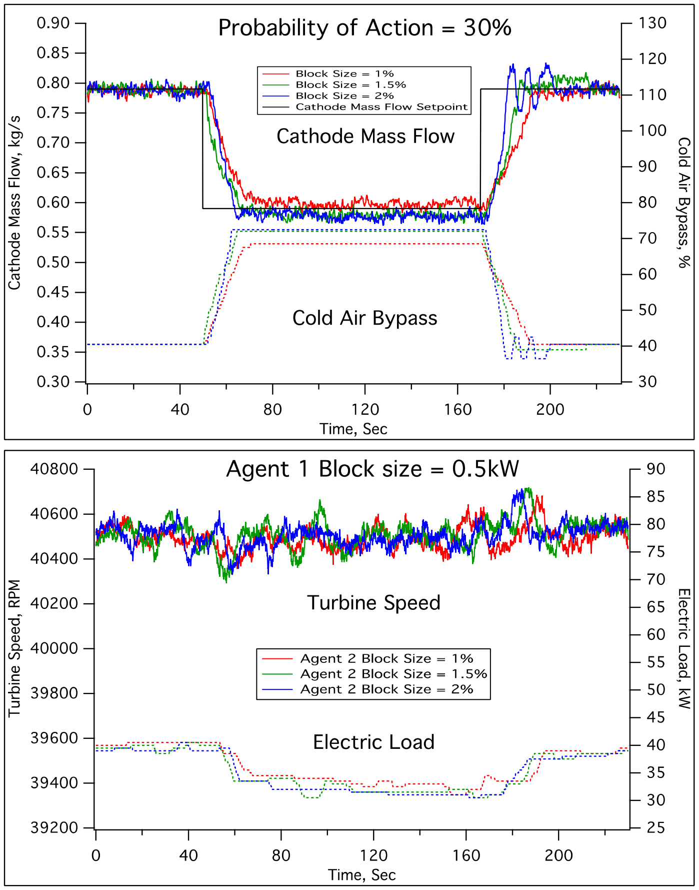


Multivariable response

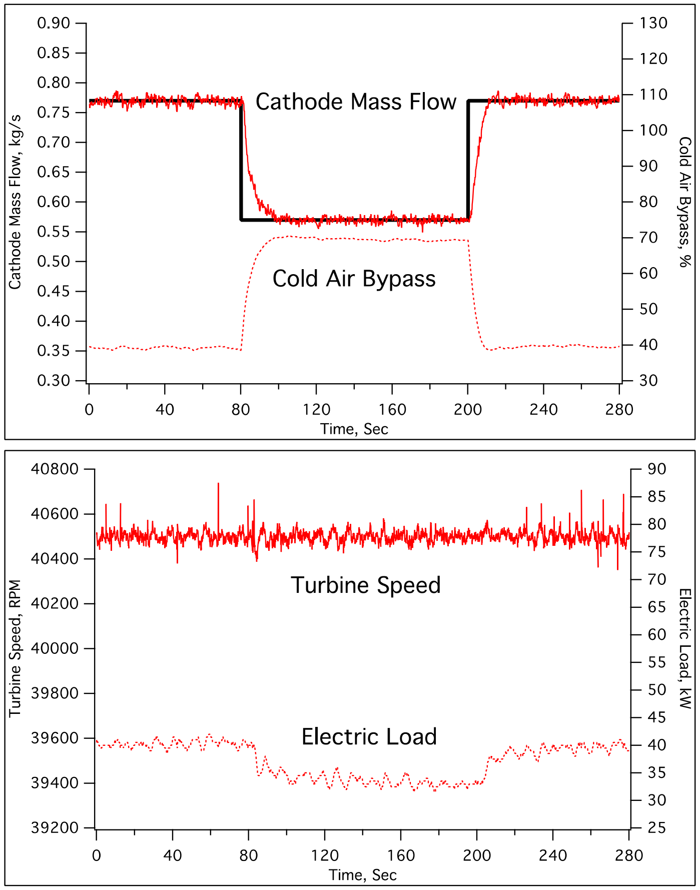


Multivariable and Stigmergic Comparison

Stigmergy response



Multivariable response



Multivariable and Stigmergic Comparison

Stigmergic Control Schema

- No modeling of the system is required
- Much simpler tuning
- In most cases the response is comparable to multivariable strategies

Multivariable Control Strategy

- Modeling and tuning of the system is a critical task
- In some cases provides a faster response
- Better disturbance rejection

Summary

Future work

Current Work

Algorithm Development

Created a resource sharing algorithm from the behavior of social insects

Physical System

Established that the algorithm can be applied to a physical system

Adaptability

Co-workers agents add redundancy that provides robustness and reconfigurability

Multiple-sensors

A control decision will be made on overlap, duplication, and reuse of sensors

MESA Team in Ames

Dan Bell (PhD grad, Iowa State U)

Zach Reinhard (PhD grad, Iowa State U)

Hyper Team in NETL

Dr. David Tucker

Dr. Farida Nor Harun

Valentina Zaccaria (PhD grad, U of Genoa)

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