Testing and Demonstrating a Stigmergic Control Strategy

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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
Hyper configuration
1. Multivariable control strategy

2. Multi-agents control solutions (Stigmergic)
Developing a Multivariable Control Schema

State Space System Modeling

\[
\begin{bmatrix}
\dot{x}_1 \\
\dot{x}_2 \\
\dot{x}_3 \\
\dot{x}_4 \\
y_1 \\
y_2
\end{bmatrix} =
\begin{bmatrix}
a_{11} & a_{12} & a_{13} & a_{14} \\
a_{21} & a_{22} & a_{23} & a_{24} \\
a_{31} & a_{32} & a_{33} & a_{34} \\
a_{41} & a_{42} & a_{43} & a_{44}
\end{bmatrix}
\begin{bmatrix}
x_1 \\
x_2 \\
x_3 \\
x_4
\end{bmatrix}
+ 
\begin{bmatrix}
b_{11} & b_{12} \\
b_{21} & b_{22} \\
b_{31} & b_{32} \\
b_{41} & b_{42}
\end{bmatrix}
\begin{bmatrix}
u_1 \\
u_2
\end{bmatrix}
\]

High Complexity in
- System Modeling
- Tuning
- Adaptability
Multivariable Control Procedure

System modeling

Validation

Off-line tuning

Experimental test

Operating point #1

Adaptability

Operating point #N

System modeling

Validation

Off-line tuning

Experimental test
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
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)
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)
Construction behavior from social insects

Insects accomplish tasks without centralized authority

Modifications to the environment are used to communicate and coordinate actions
Computational agents represent insects

Agents imitates the construction behavior of social insects

Each agent takes independent decisions
**Flexibility**  
Agent can easily be added or taken away

**Adaptability**  
Overcome changes in the environment
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
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
Stigmergic - Tuning Parameter Results

Agent 1 Rise Times

Agent 2 Rise Times

Agent 1 Settling Times

Agent 2 Settling Times
Multivariable and Stigmergic Comparison

Stigmergic response

Multivariable response

Agent 1 Block Size = 0.5kW

Agent 2 Block size = 1.5%

Cathode Mass Flow

Cold Air Bypass

Turbine Speed

Electric Load

Turbine Speed

Electric Load

Cathode Mass Flow

Cold Air Bypass
Multivariable and Stigmergic Comparison

Stigmergy response

Probability of Action = 30%

Cathode Mass Flow

Cold Air Bypass

Multivariable response

Cathode Mass Flow

Cold Air Bypass

Agent 1 Block size = 0.5kW

Turbine Speed

Electric Load

Agent 2 Block Size = 1%
Agent 2 Block Size = 1.5%
Agent 2 Block Size = 2%

Turbine Speed

Electric Load
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
Future 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

Current Work
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