Autonomic Microgrids ?

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Newcastle University

CESI National Centre for Energy Systems Integration

Overview

- Autonomic Microgrids and Self* Operation
- Technical Zoning
- Algorithm Selection
- Market Zoning
- Self Organising Architectures and Cyber Security
- National Centre for Energy Systems Integration

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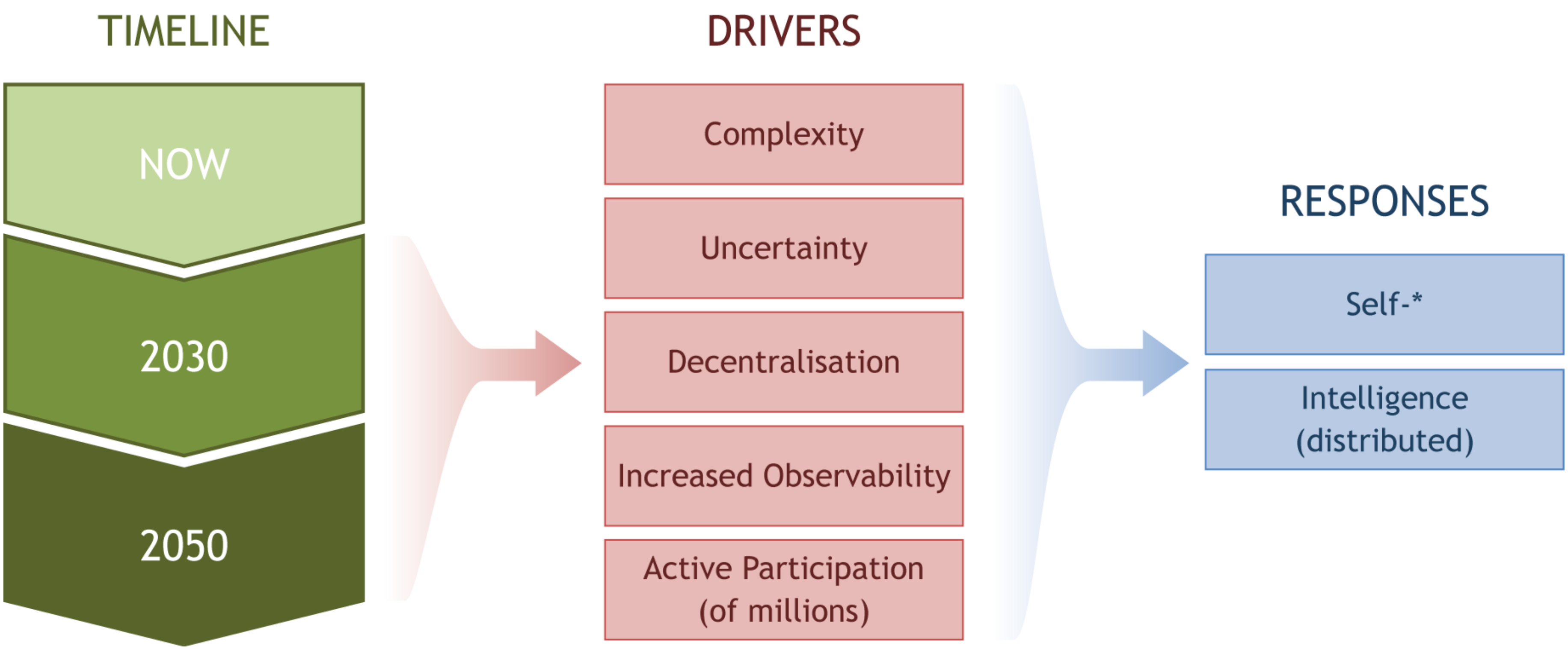
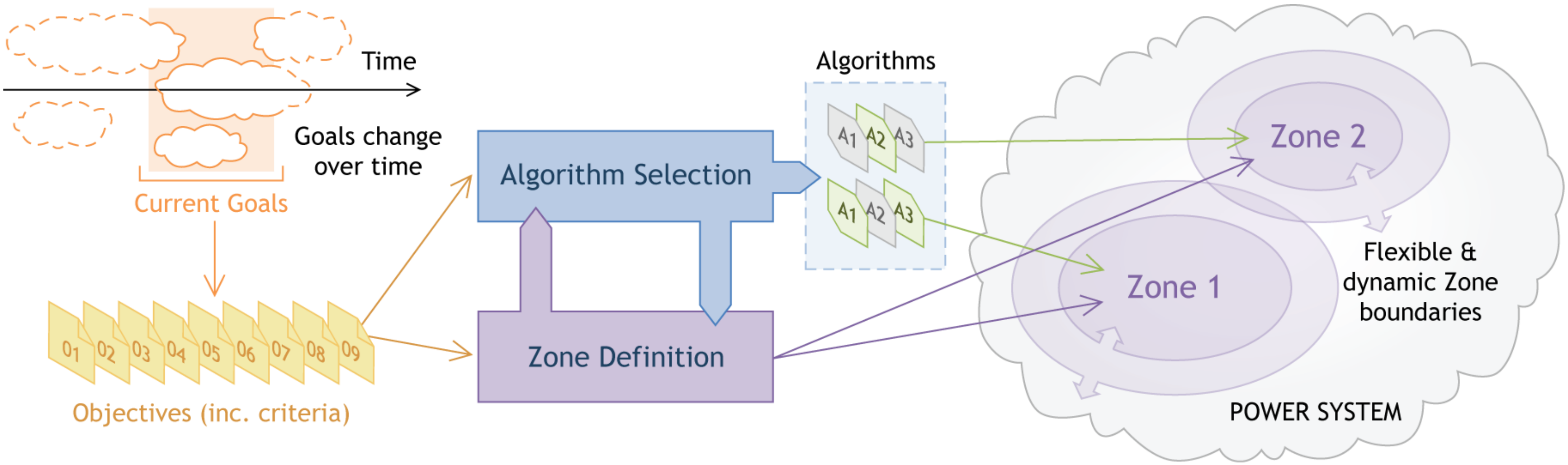
Drivers


TIMELINE
NOW
2030
2050
DRIVERS
Complexity
Uncertainty
Decentralisation
Increased Observability
Active Participation
(of millions)
RESPONSES
Self-*
Intelligence
(distributed)

Overarching Research Question

Can a fully distributed intelligence and control philosophy deliver the future flexible grids required to facilitate the low carbon transition, allow for the adoption of emerging game-changing network technologies and cope with the accompanying increase in uncertainty and complexity?

Self* Network Operation and Control Schematic



II. How to zone ? –(a)

Zoning methodology

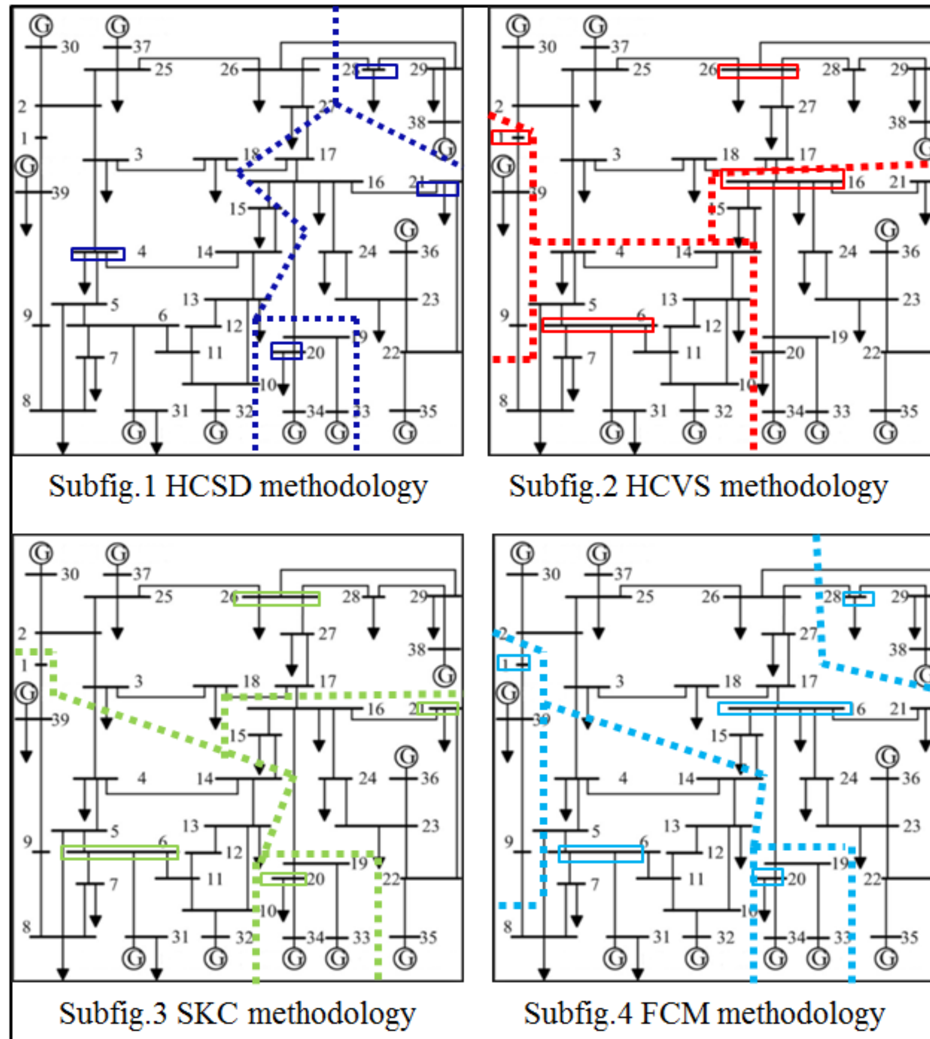
- Proximity metric: definition of distance among buses
- Definition of merging criteria
- Clustering validation criteria

- Zonal centroid identification (pilot node)

Zoning methodologies (examples of existing and own ones):

- Hierarchical clustering –single distance (HCSD)
- Hierarchical clustering –MVAr control space (HCVS)

- *Spectral Clustering (SKC)*
- *Fuzzy Clustering (FCM)*



Subfig.1 HCSD methodology

Subfig.2 HCVS methodology

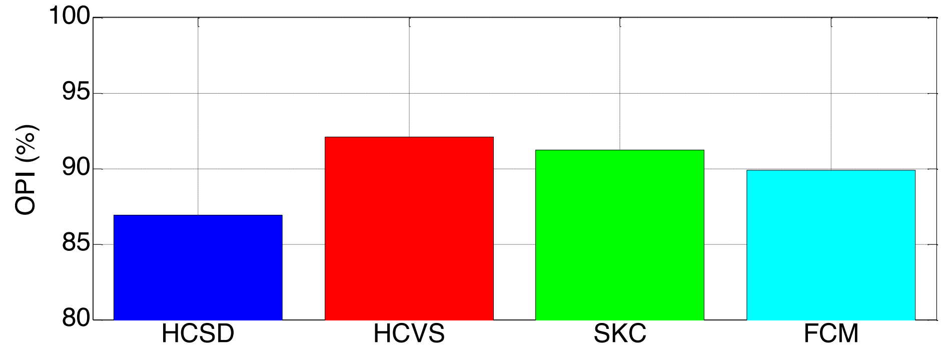
Subfig.3 SKC methodology

Subfig.4 FCM methodology

II. How to zone? –(b)

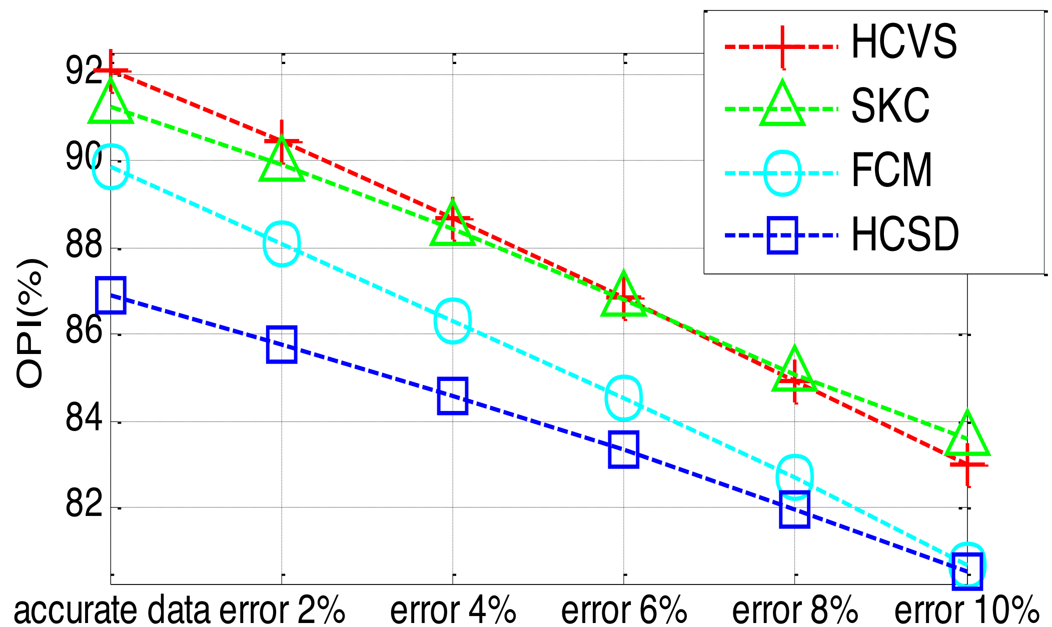
Performance of a zoning decision

-a greater performance signifies reduced losses & enhanced security



Robustness of a zoning decision

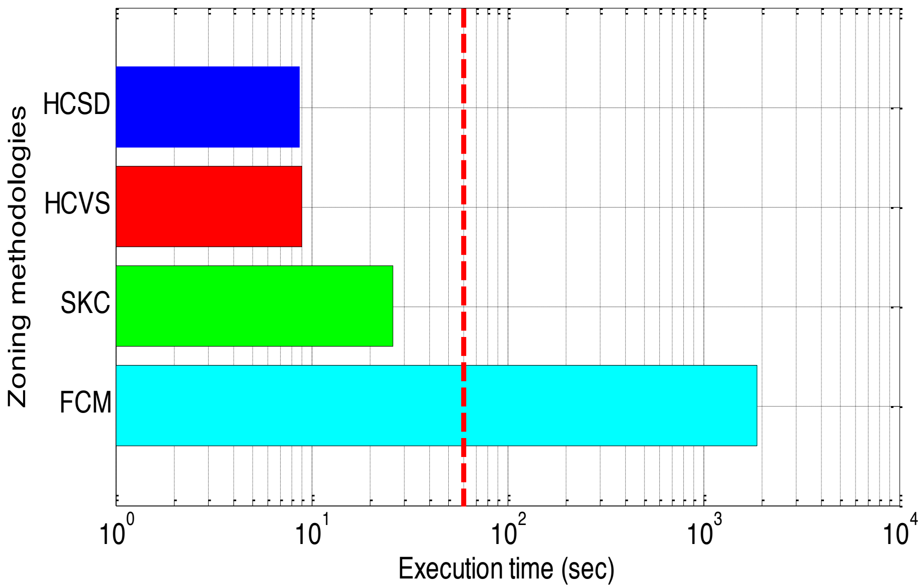
-testing the effect of uncertainty on the measurements (e.g. imperfect prediction, noisy or corrupted data)



III. Static vs. adaptive zoning.

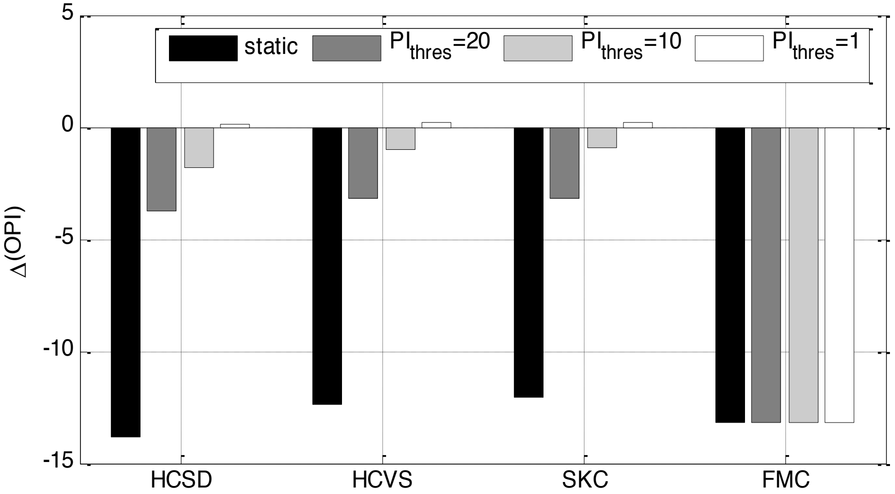
Questioning the feasibility.

- Fast enough (<1 min) for large scale network (e.g. 2383 buses test network) ?
- Availability of measurement and telecommunication infrastructure ?

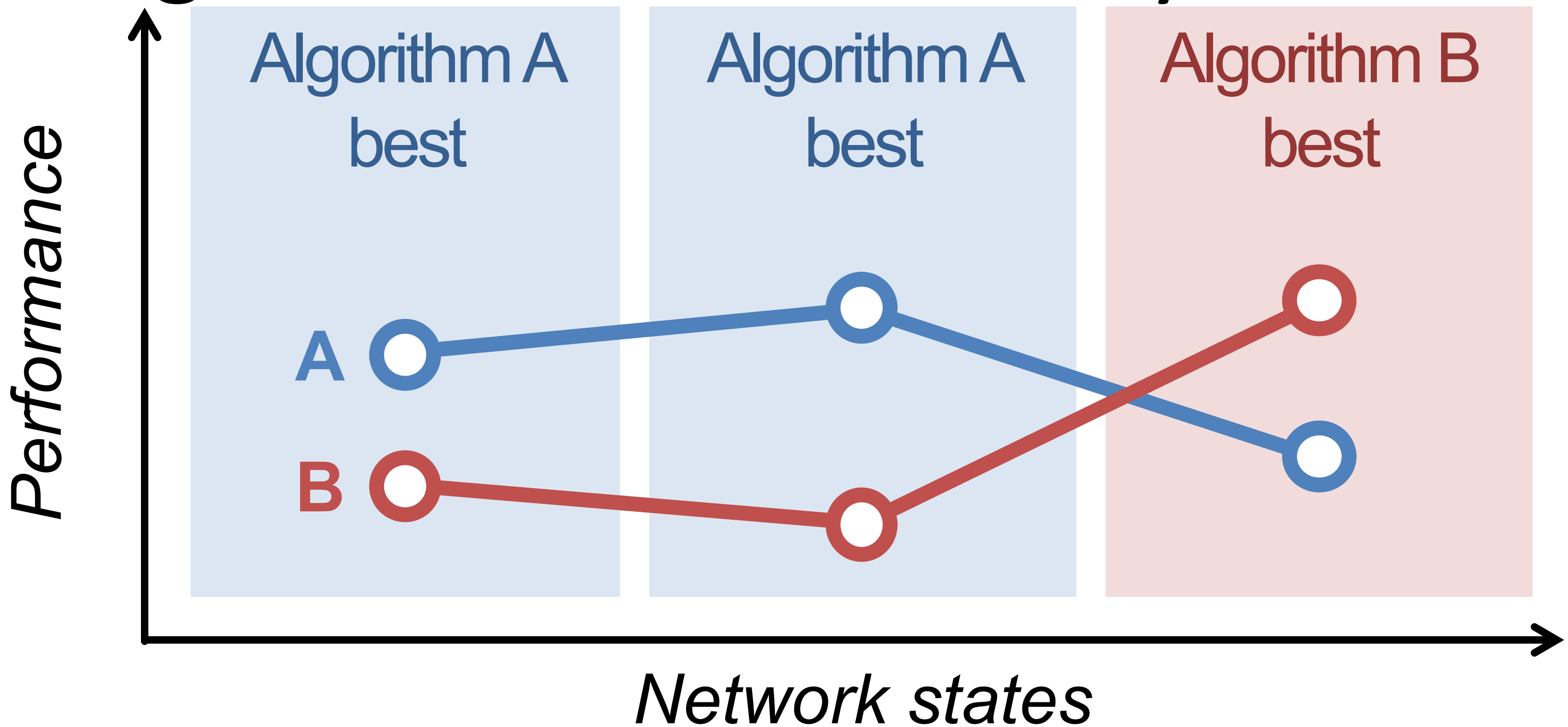


Questioning the value.

- Performance enhancement vs. reconfiguration threshold



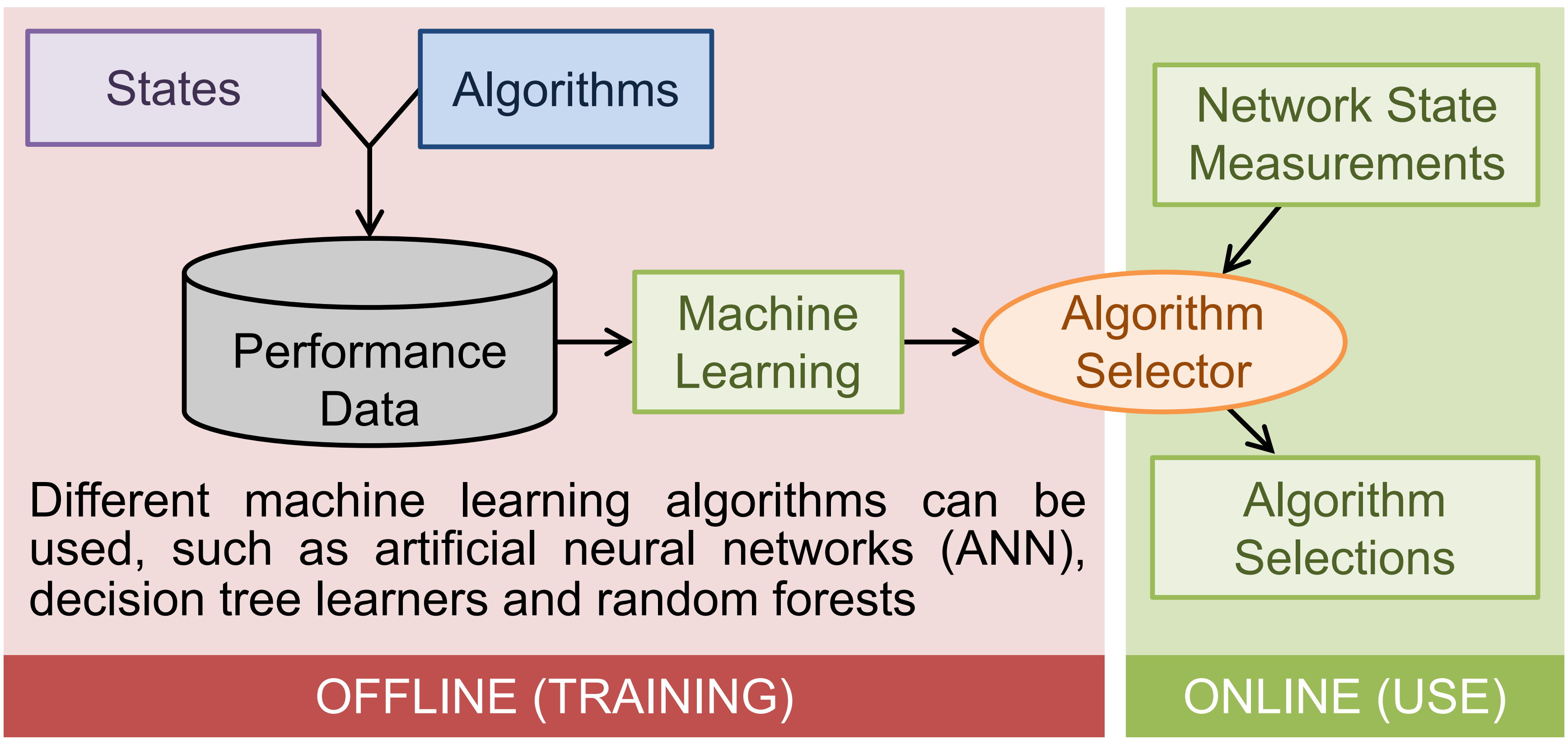
Algorithm Selection: Why Do It?



Potential to provide **better performance** by **selecting algorithms for each state**, instead of using **one algorithm for all states**

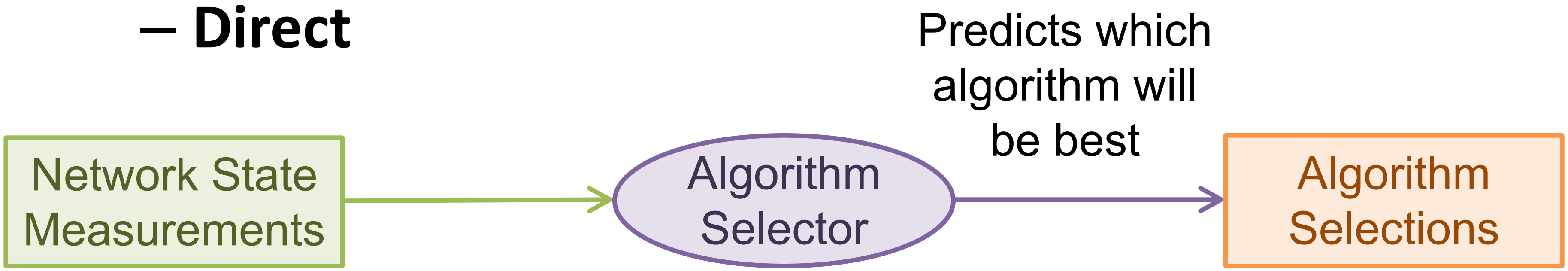
Building Algorithm Selectors

- Create an **algorithm selector** to exploit link between network state and algorithm performance
- Use machine learning to create the selector

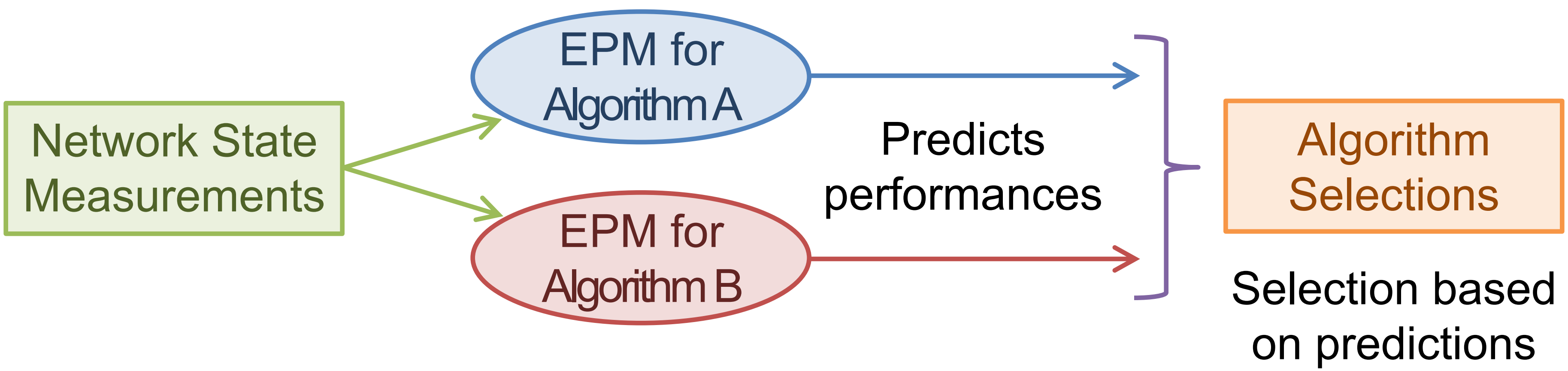


Building Algorithm Selectors

- Creation of algorithm selectors already established in computer science applications
- Two main types:
  - **Direct**



  - **EPM-based** (Empirical Performance Model)



Application: Power Flow Management

- Additional Distributed Generators (DGs) can cause overloaded network branches

- Power Flow Management:
  - Active approach (Active Network Management)
  - Control DG outputs to mitigate overloads

- Ideally: **minimise overloads** while **minimising DG curtailment**

Application: Power Flow Management

Power flow management algorithms

5

implemented & tested

Case study power systems

4

used for testing

Varying system states

40k+

simulated per system

Algorithm selector designs

20k+

developed & evaluated

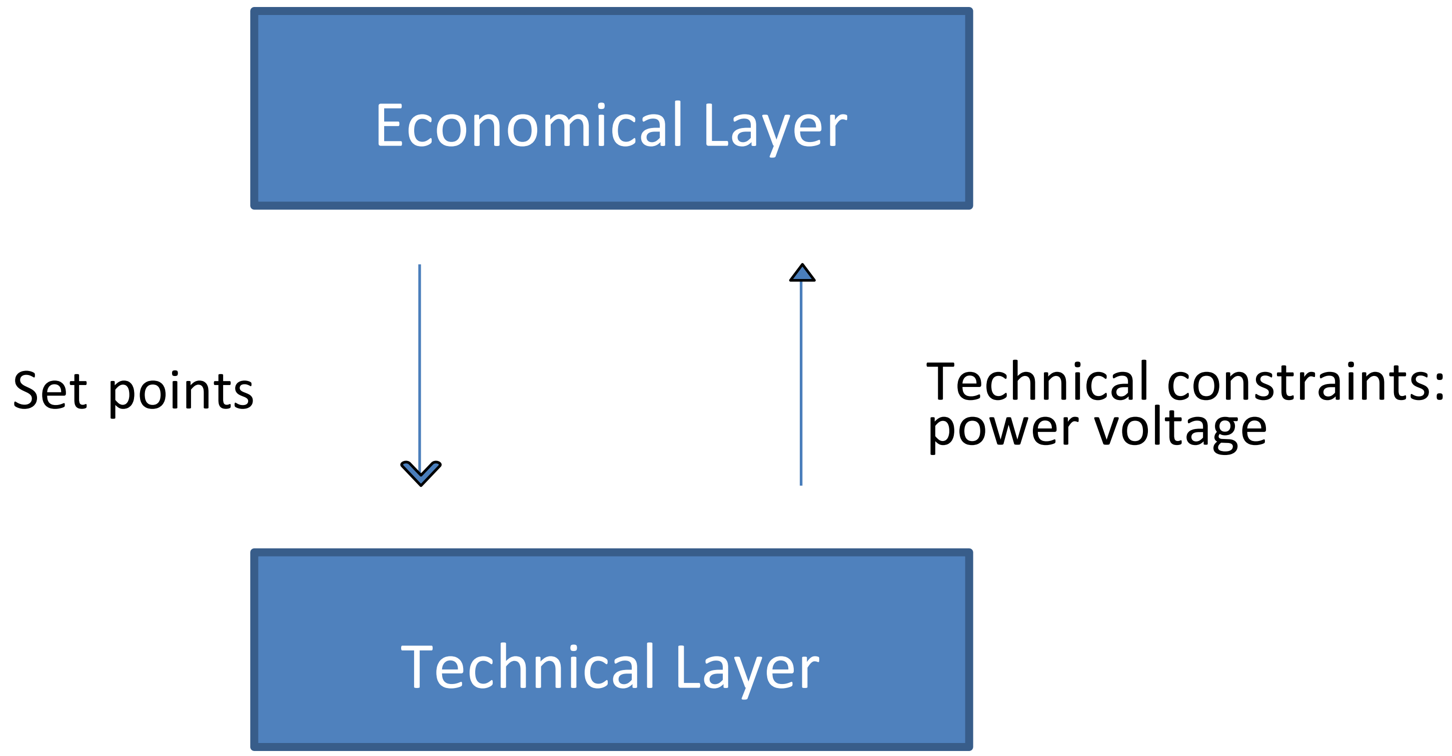
Application: Power Flow Management

- Example: IEEE 57-bus system, 10,000 states

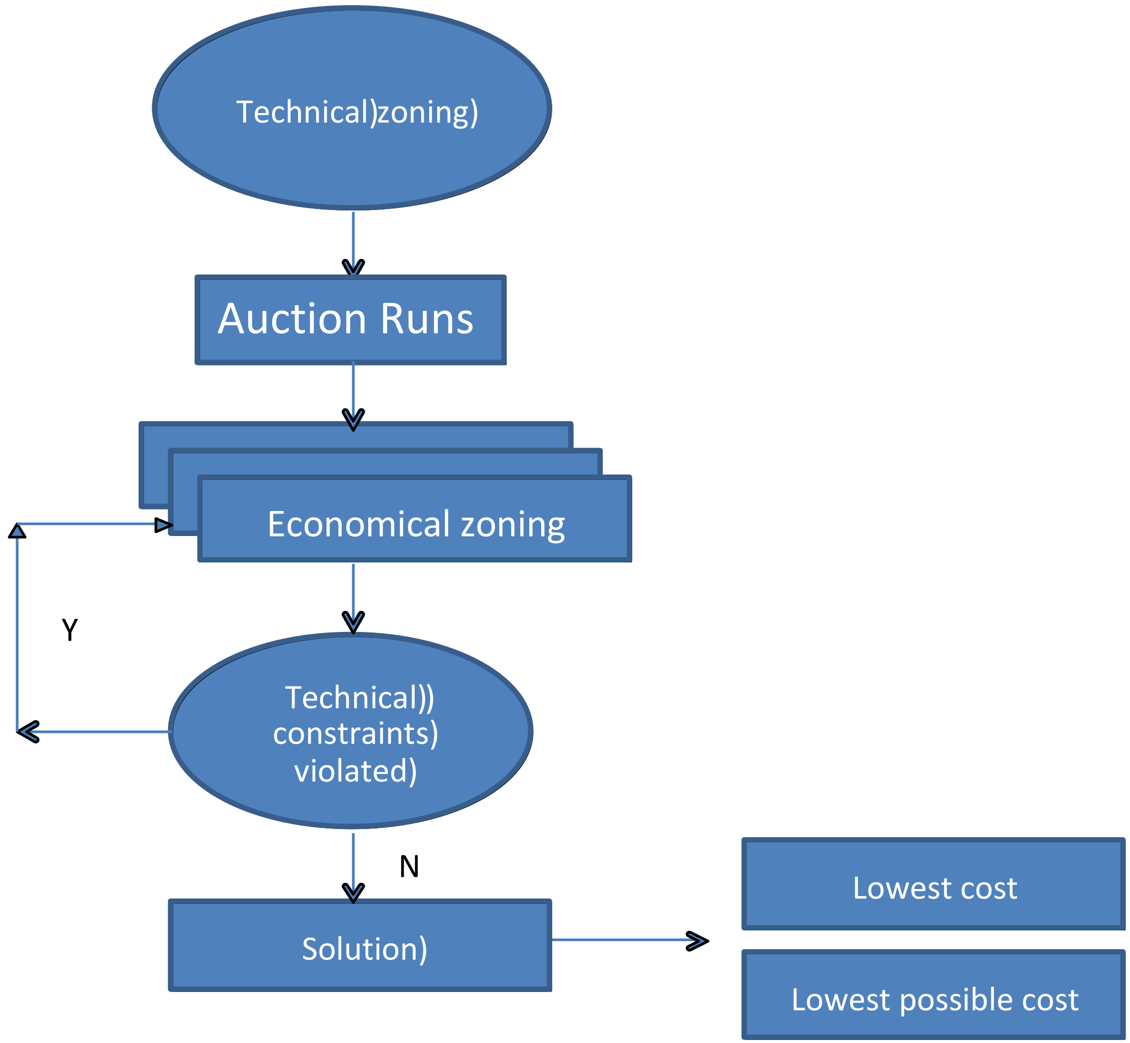
Algorithm / Selector	No. of overloads (count)	Curtailed energy (MWh)
Best Individual Algorithm (OPF)	1367	749,900
Best Direct Selector	771	900,734
Best EPM-based Selector	772	926,646
Optimal Selections	768	821,087

- Algorithm selection reduces the number of overloads

Economical and Technical Layers



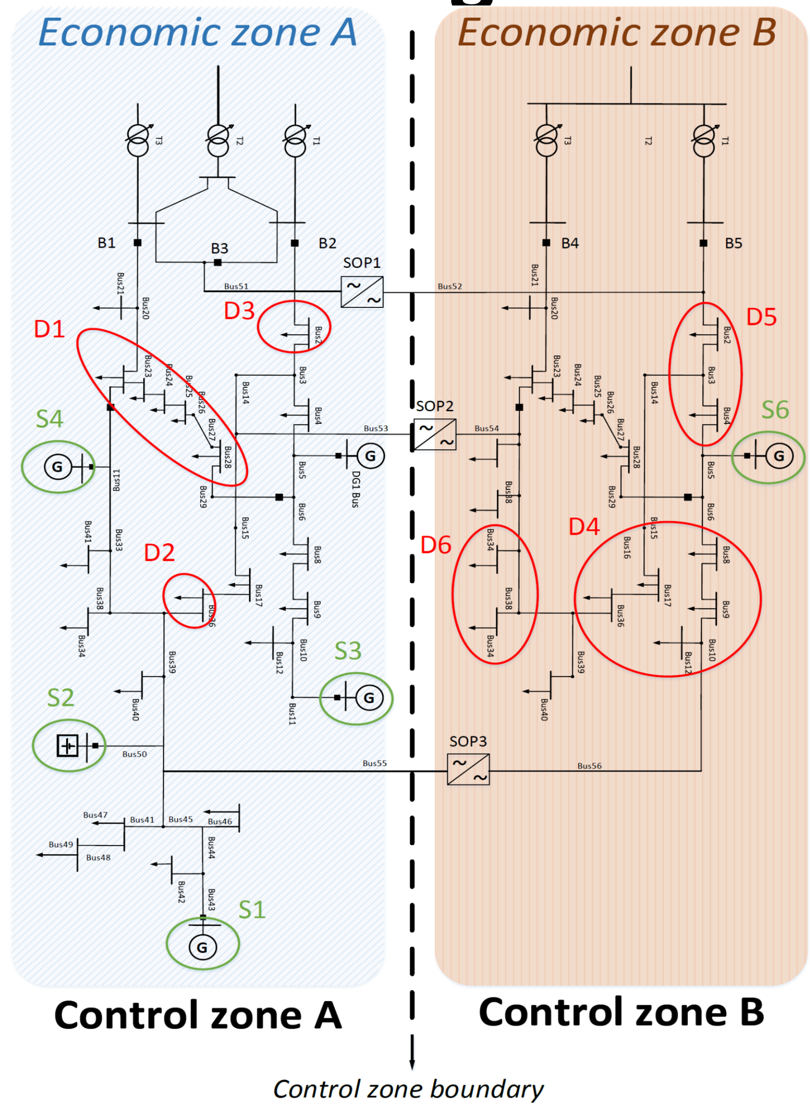
Interaction between the two Layers



An example – initial zoning

- 11 bidders participating in the auction – six demands (D1-D6) and five suppliers (S1-S5).

- Overall demand in Control zone A is 12.5 MW and 10 MW in Control zone B.



Offers and bids in zone A

Demand	MW	Cost (pence/MW)
Demand 1	5	120
Demand 2	2.5	100
Demand 3	5	90
Suppliers	**MW**	**Cost (pence/MW)**
Supplier 1	2.5	140
Supplier 2	5	130
Supplier 3	7.5	130
Supplier 4	12.5	90
Supplier 4	2.5	80

Using a two-sided uniform-price auction, Supplier 4 delivers 12.5 MW to Demands 1, 2 and 3 at a price of 90 pence. Before using the flexible zoning structure, the cost in Economic zone A alone would be 1125 pence (12.5 MW*90 pence).

Offers and bids in zone B Initial zoning

Demand	MW	Cost (pence/MW)
Demand 4	5	80
Demand 5	2.5	50
Demand 6	2.5	40
Suppliers	**MW**	**Cost (pence/MW)**
Supplier 5	12.5	50
Supplier 5	10	40
Supplier 5	10	40

Again, using a two-sided uniform-price auction Supplier 5 delivers 10 MW to Demands 4, 5 and 6 at a price of 40 pence. At this price, the energy cost in Economic zone B alone would be 400 pence (10 MW*40 pence). Together with Economic zone A, **total energy cost would be 1525 pence.**

Suggestion 1 – lowest overall cost

Zones	MW	Cost (pence/MW)
Economic Zone A (new zone)		
Demand 1	5	120
Demand 3	5	90
Demand 5	2.5	50
Supplier 5	12.5	50
Economic Zone B (new zone)		
Demand 2	2.5	100
Demand 4	5	80
Demand 6	2.5	40
Supplier 5	10	40
Total cost		1025

12.5*50+10*40 = 625+400= 1025 pence.

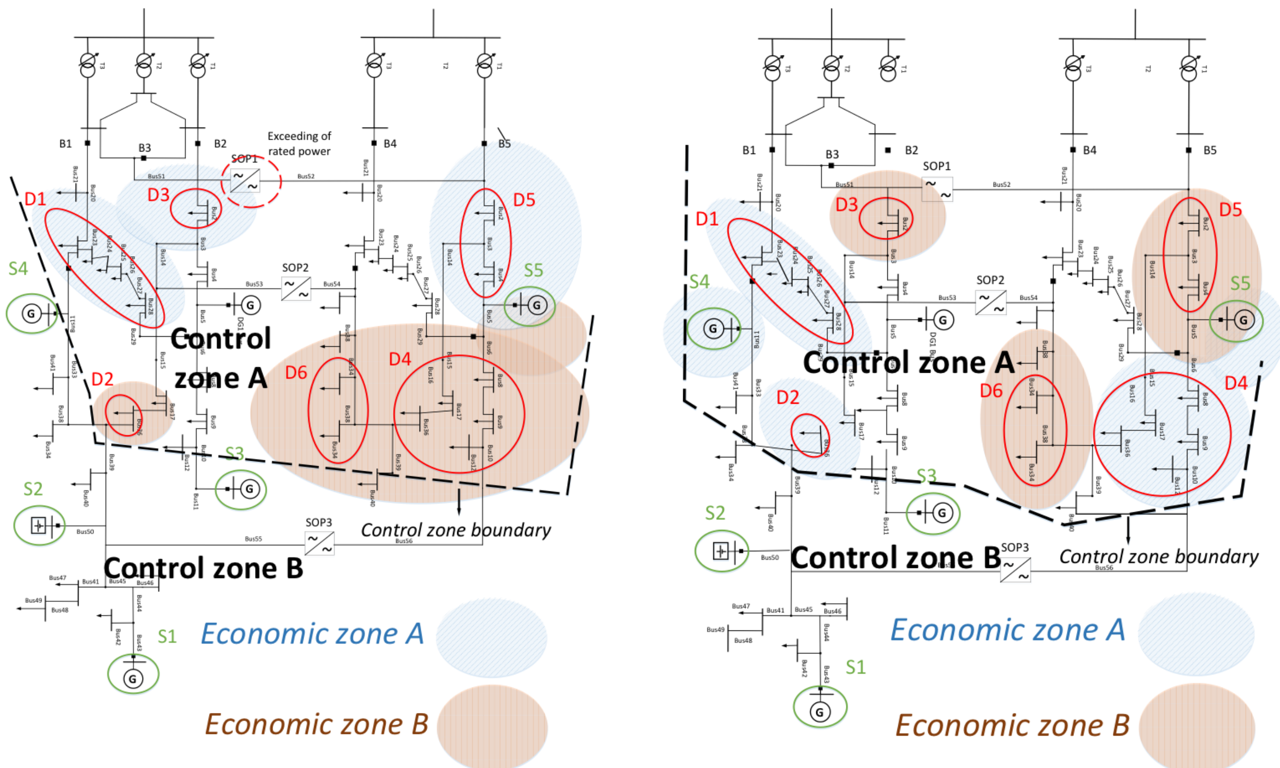
Suggestion 2 – second-lowest overall cost
(If Suggestion 1 is not technically feasible)

Zones	MW	Cost (pence/MW)
Economic Zone A (new zone)		
Demand 1	5	120
Demand 2	2.5	100
Demand 4	5	80
Supplier 4	2.5	80
Supplier 5	10	40
Economic Zone B (new zone)		
Demand 3	5	90
Demand 5	2.5	50
Demand 6	2.5	40
Supplier 5	10	40
Total cost		1400

12.5*80+10*40 = 1000+400 = 1400 pence.

Decision

- The Technical Layer rejects Economic Layer Suggestion 1.
- Economic Layer Suggestion 2 is feasible. Suggestion 2 is accepted by Technical Layer but is an improvement on initial suggestion.

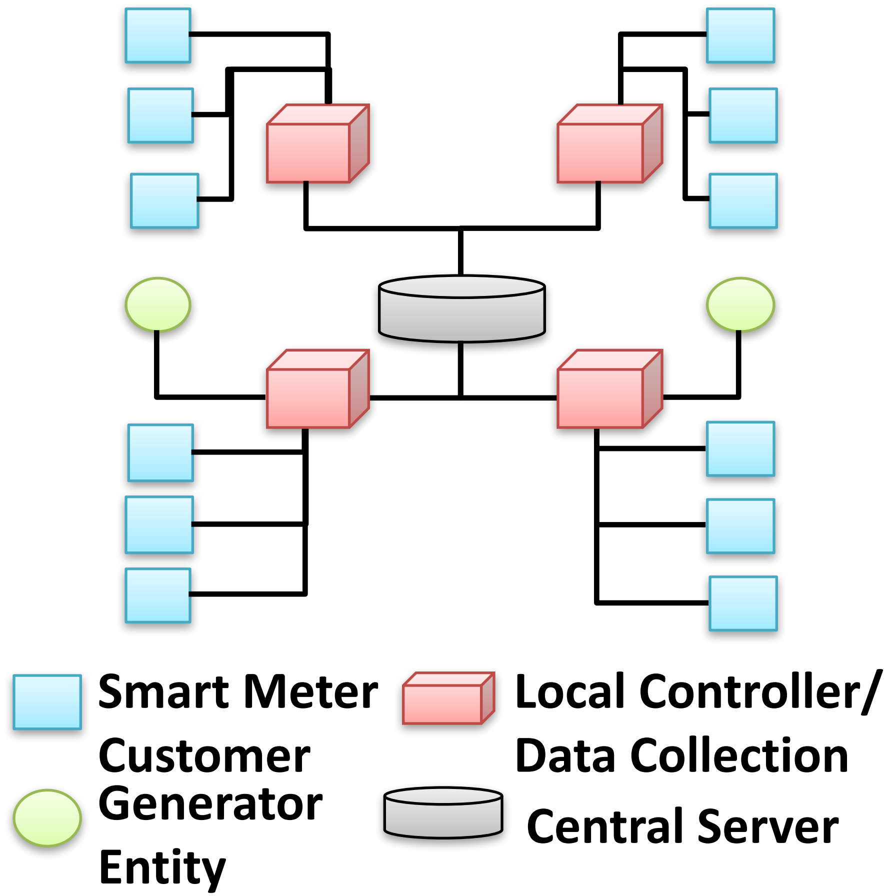


(a) Suggestion 1 (b) Suggestion 2

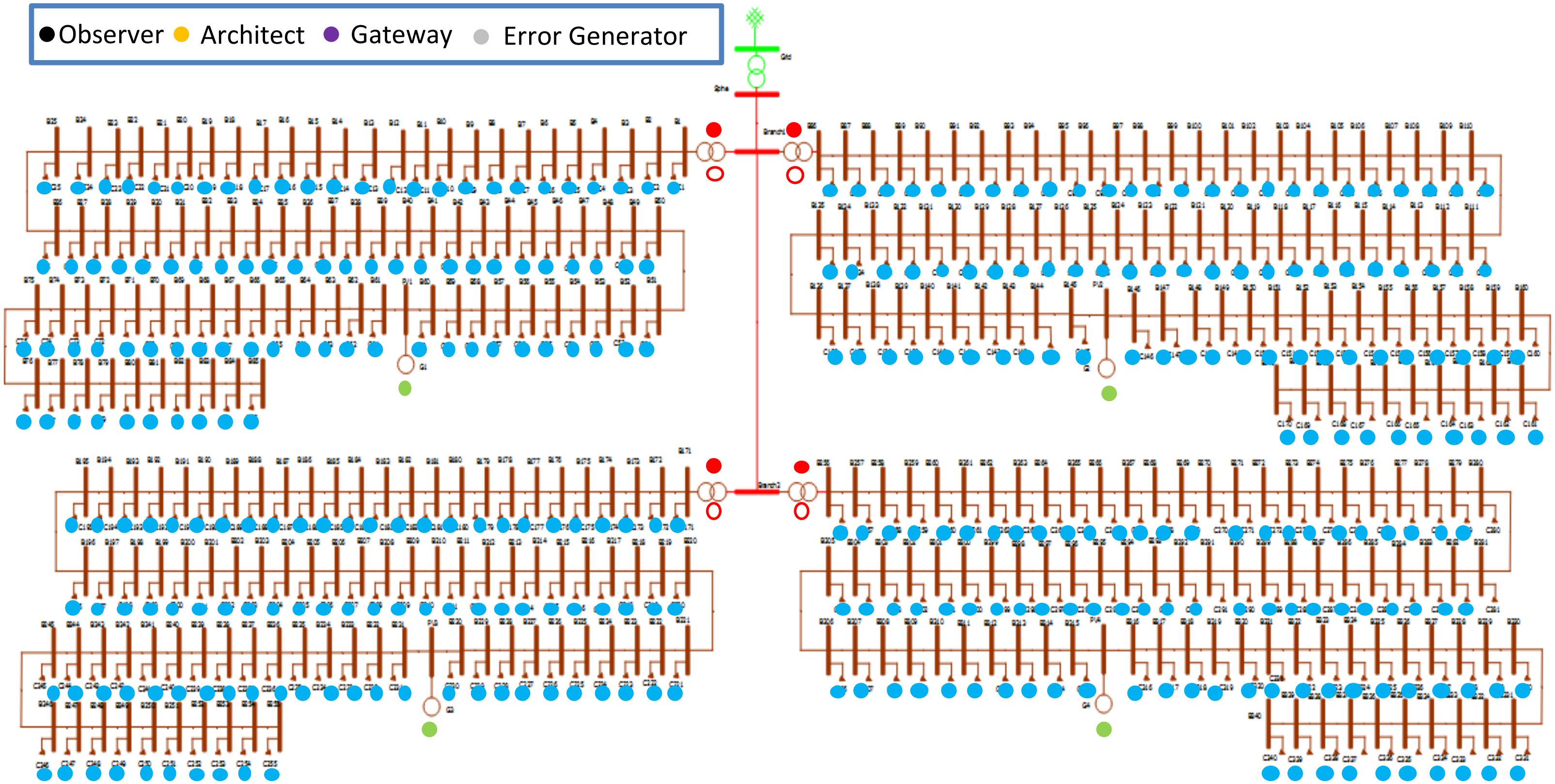
Fig. 5 Suggested zones after re-configuration

Self-Organising Architectures

- An Agent based architecture
- Self-Organising properties to respond to attacks
- Operates in three stages
  - Initialisation
  - Performance Monitoring
  - Decision Making and reconfiguration
- Fuzzy based Decision making engine
- Interfaces with Matpower for load flow calculation



Network Configuration



340 Customers with profiles

4 PV Generators with profiles

4 Active Aggregates (4 Dormant)

4 Central Core Agents

Attack Strategies

- All attacks are based on low-rate Denial of Service attacks
- Selected customer agents act as the attackers
- Aggregate Agents as controllers are the targets
- Two levels of attacker sophistication
  - Static: Low level of sophistication, attacker selects a fixed target
  - Adaptive: An escalated state, attack traffic redirects after an architecture transition

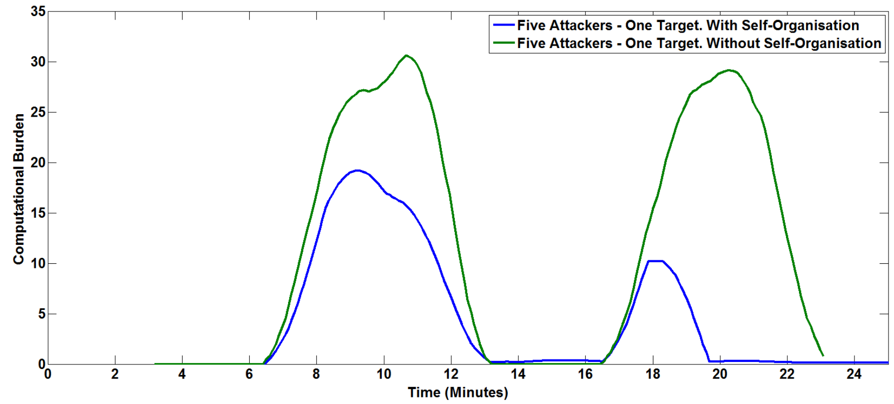
29 Combinations of Attack Strategy, Intensity and Sophistication

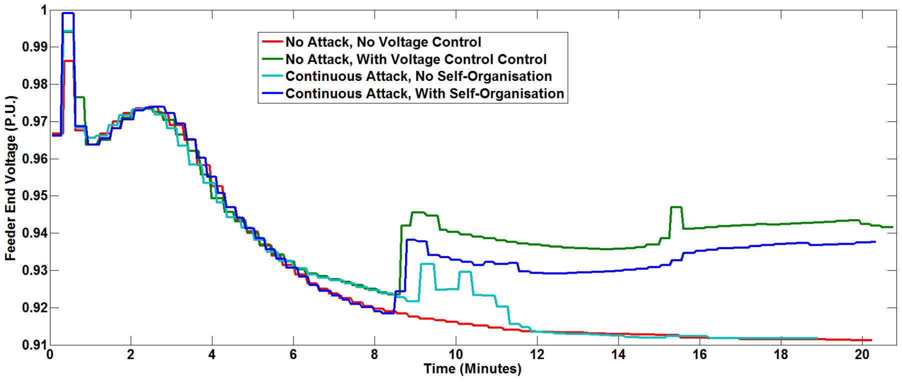
- Burst Attack: Attack traffic transmitted for 250 seconds
- Continuous Attack: Attack traffic transmitted once triggered until the end of the simulation
- Sequential Attack: Two Burst instances at critical stages of the control process

Attacks timed to coincide with voltage control signals

Responding to an attack

- The architect is informed the impact on performance metrics.
- All metrics are combined to form a value for Computational Burden.
- A fuzzy based decision making engine monitors the burden and its rate of change.
- If necessary architectural transitions are initiated to redistribute connections, replace agents or increase aggregate capacity
- Aiming to improve control performance through easing load on the communication network





Physics

Mechanical Engineering

Electrical Engineering

Geology

CESI

National Centre for **Energy Systems Integration**

Economics

Anthropology

Mathematics

Computer Science

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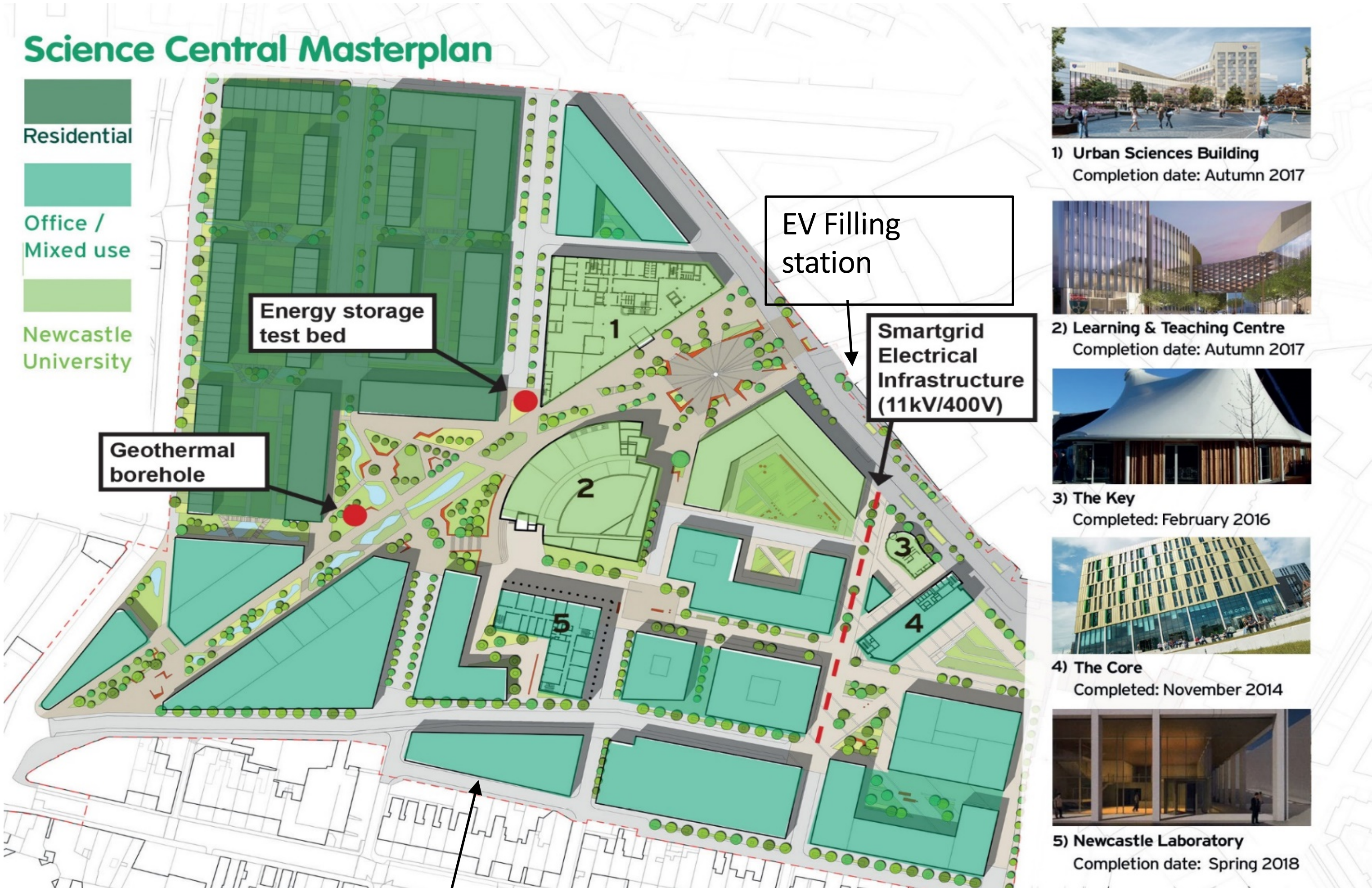
Urban Microgrid in Newcastle



CHP system
Thermal Storage
Heat and Cool Network

Conclusions

- Autonomic Microgrids and Self* promising
  - Dynamic Zones, Algorithm Selection
- Multiple Microgrids ?
- Decentralised Markets
- Cyber Security needs more work
  - Model the attackers
- Multi Vector Microgrids

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