Autonomic Microgrids?

Professor Phil Taylor
Siemens Professor of Energy Systems
Director of the EPSRC National Centre for Energy Systems Integration

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Overview

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

- 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)
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
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

Different machine learning algorithms can be used, such as artificial neural networks (ANN), decision tree learners and random forests

**OFFLINE (TRAINING)**

**ONLINE (USE)**
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 implemented & tested: 5
- Case study power systems used for testing: 4
- Varying system states simulated per system: 40k+
- Algorithm selector designs developed & evaluated: 20k+
Application: Power Flow Management

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

<table>
<thead>
<tr>
<th>Algorithm / Selector</th>
<th>No. of overloads (count)</th>
<th>Curtained energy (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best Individual Algorithm (OPF)</td>
<td>1367</td>
<td>749,900</td>
</tr>
<tr>
<td>Best Direct Selector</td>
<td>771</td>
<td>900,734</td>
</tr>
<tr>
<td>Best EPM-based Selector</td>
<td>772</td>
<td>926,646</td>
</tr>
<tr>
<td>Optimal Selections</td>
<td>768</td>
<td>821,087</td>
</tr>
</tbody>
</table>

- Algorithm selection reduces the number of overloads
Economical and Technical Layers

Economical Layer

Set points

Technical Layer

Technical constraints: power voltage
Interaction between the two Layers

- Technical zoning
  - Auction Runs
    - Economical zoning
      - Technical constraints violated
        - Solution
          - Lowest cost
          - Lowest possible cost
      - Y
    - N
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.
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

<table>
<thead>
<tr>
<th>Demand</th>
<th>MW</th>
<th>Cost (pence/MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand 4</td>
<td>5</td>
<td>80</td>
</tr>
<tr>
<td>Demand 5</td>
<td>2.5</td>
<td>50</td>
</tr>
<tr>
<td>Demand 6</td>
<td>2.5</td>
<td>40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Suppliers</th>
<th>MW</th>
<th>Cost (pence/MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 5</td>
<td>12.5</td>
<td>50</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>10</td>
<td>40</td>
</tr>
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</table>

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**

<table>
<thead>
<tr>
<th>Zones</th>
<th>MW</th>
<th>Cost (pence/MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic Zone A (new zone)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand 1</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td>Demand 3</td>
<td>5</td>
<td>90</td>
</tr>
<tr>
<td>Demand 5</td>
<td>2.5</td>
<td>50</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>12.5</td>
<td>50</td>
</tr>
<tr>
<td>Economic Zone B (new zone)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand 2</td>
<td>2.5</td>
<td>100</td>
</tr>
<tr>
<td>Demand 4</td>
<td>5</td>
<td>80</td>
</tr>
<tr>
<td>Demand 6</td>
<td>2.5</td>
<td>40</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>10</td>
<td>40</td>
</tr>
</tbody>
</table>

Total cost = 1025 pence.

\[12.5 \times 50 + 10 \times 40 = 625 + 400 = 1025 \text{ pence.}\]
Suggestion 2 – second-lowest overall cost
(If Suggestion 1 is not technically feasible)

<table>
<thead>
<tr>
<th>Zones</th>
<th>MW</th>
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<tr>
<td>Economic Zone A (new zone)</td>
<td></td>
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</tr>
<tr>
<td>Demand 4</td>
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<td>80</td>
</tr>
<tr>
<td>Supplier 4</td>
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<td>80</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Economic Zone B (new zone)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand 3</td>
<td>5</td>
<td>90</td>
</tr>
<tr>
<td>Demand 5</td>
<td>2.5</td>
<td>50</td>
</tr>
<tr>
<td>Demand 6</td>
<td>2.5</td>
<td>40</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Total cost</td>
<td></td>
<td>1400</td>
</tr>
</tbody>
</table>

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
Urban Microgrid in Newcastle

Science Central Masterplan

- Residential
- Office / Mixed use
- Newcastle University

**EV Filling station**

- Energy storage test bed
- Geothermal borehole
- Smartgrid Electrical Infrastructure (11kV/400V)

**CHP system**
- Thermal Storage
- Heat and Cool Network

1) Urban Sciences Building
   Completion date: Autumn 2017

2) Learning & Teaching Centre
   Completion date: Autumn 2017

3) The Key
   Completed: February 2016

4) The Core
   Completed: November 2014

5) Newcastle Laboratory
   Completion date: Spring 2018
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