Centre for Energy and Environmental Markets

CSIRO ISS Seminar Series

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Decentralised coordination of distributed power system resources using evolutionary programming

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UNSW Centre for Energy + Environmental Markets

Established…

- *to formalise* growing interest + interactions between UNSW researchers in Engineering, Commerce + Economics… + more
- *through UNSW Centre* providing Australian research leadership in interdisciplinary design, analysis + performance monitoring of energy + environmental markets, associated policy frameworks
- *in the areas* of
  - Physical energy markets (with an initial focus on ancillary services, spot market + network services for electricity + gas)
  - Energy-related derivative markets (financial + environmental including interactions between derivative and physical markets)
  - Policy frameworks and instruments in energy and environment
  - Economic valuation methodologies
  - **Experimental market platforms and AI 'intelligent agent' techniques to aid in energy + environmental market design**

Tools for assessing market design + structure

- Economics – eg. general competitive market theory
- Experience with existing, similar markets
- 'Common-sense' assessment
- Mathematical analysis – Cournot + Bertrand paradigms, game theory…
- **Experiments**
  - Field trials, demonstration programs
  - Simulation
    - 'Trial + error' simulations to explore possible outcomes
    - Simulations guided by 'intelligent' market participants

      Experimental subjects

      Intelligent software agents

The emerging electricity industry

- Drivers
  - Market oriented restructuring now underway in much of the world
  - Growing potential of distributed resources
  - Increasingly pressing environmental concerns

- Outcomes for power systems
  - Likely increasingly physically distributed – many smaller-scale generation and active demand-side resources
  - More organisationally decentralised – decision making devolved to far greater numbers and diversity of industry participants

Traditional power system operation

- Operation to minimise the risk-weighted cost of electricity supply to meet given demand + required level of security
    - Approximate time scales of 5 min to a year
- Challenges
    - Physical power system characteristics: *supply/demand* balance at all times in all locations, no cost-effective storage
    - Complex resources characteristics
        - Stochastic behaviour
        - Inter-temporal links (eg. Hydro, ramp rates)

- *Analysis tools*
    - Use time decomposition – economic dispatch, unit commitment, fuel scheduling (inter-temporal links are key challenge)
    - LP, DP, Lagrangian Relaxation, GA….

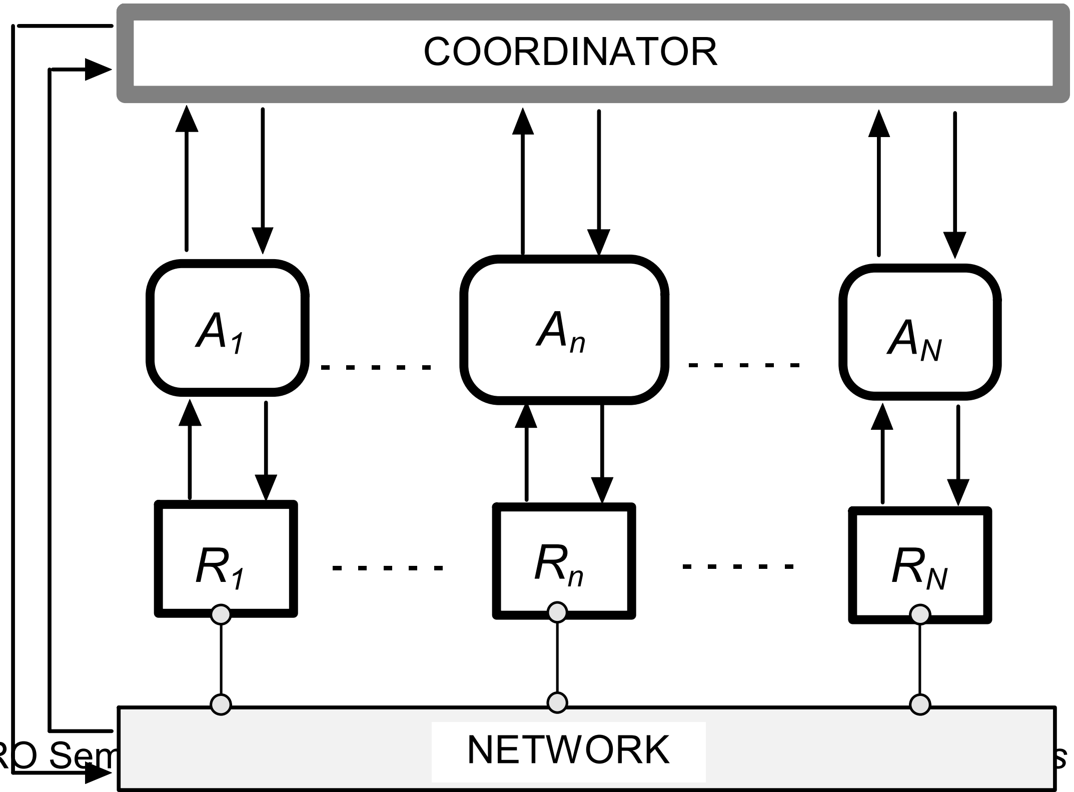
  => Centralised dispatch solutions for a small number of large supply-side resources

Decentralised power system coordination

- Emerging challenges with distributed resources + decentralisation
  - Potentially far greater numbers
  - Demand-side resources (eg. Load management)
  - More variable + stochastic resources (eg. Wind, PV)
  - *Independent participants with individual objectives*
- Options for power system operation
  - *Traditional centralised control* (DRs treated as uncontrolled variation)
  - *Centralised control* with spot pricing– DRs can self-dispatch
  - *Decentralised coordination* –resources can actively direct dispatch via
    - Bilateral contracting
    - **Electricity spot markets**
- New types of analysis tools reqd
  - Individual participant behaviour
  - Market coordination – design (rules) + structure of markets

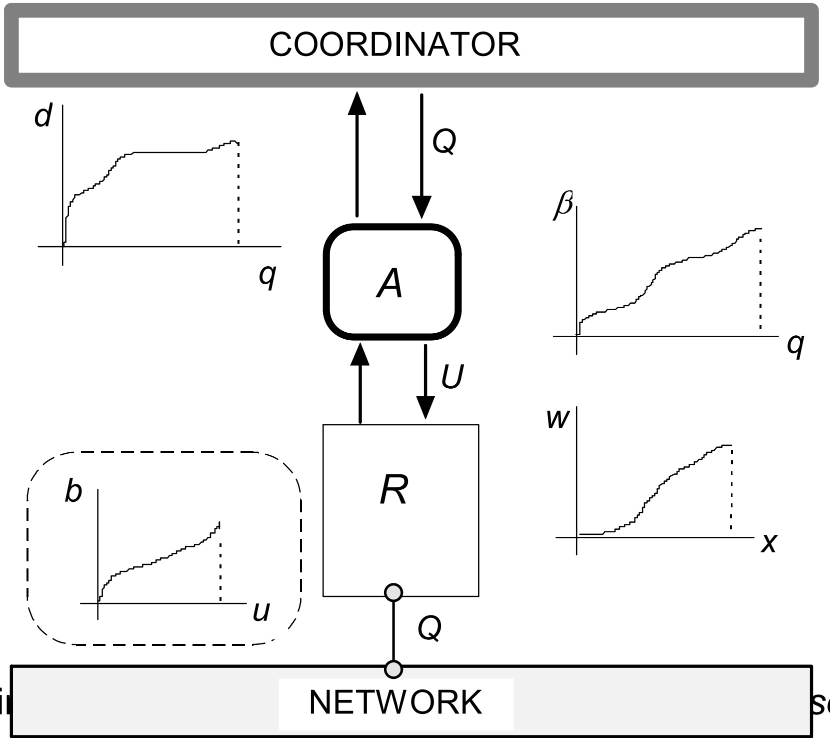
Power system model

- Resources – ITLs (state), stochastic behaviour (Markov chains), aggregations of different plant (eg. Hydro + thermal)
- Network – single bus, radial network with transport model…
- Agents – control resource, communicate with coordinator, social/individual objs
- System coordinator – max. declared benefits of energy trading s.t. constraints

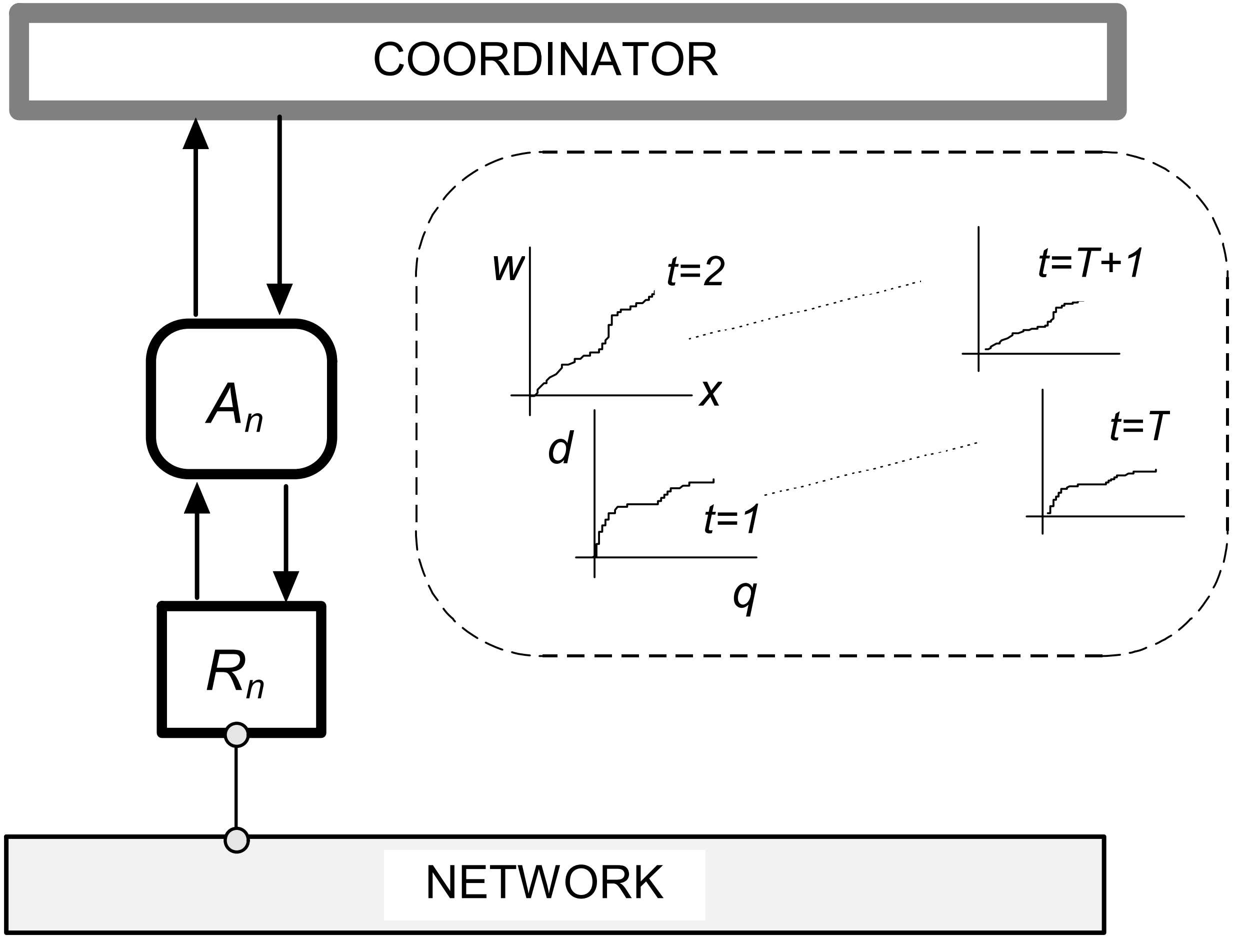


Agent model

- b – benefit function wrt control actions u
- **w – future benefit function wrt state x**
- **B – combined benefit function wrt elec. flow q**
- **d – declared benefit function wrt q**

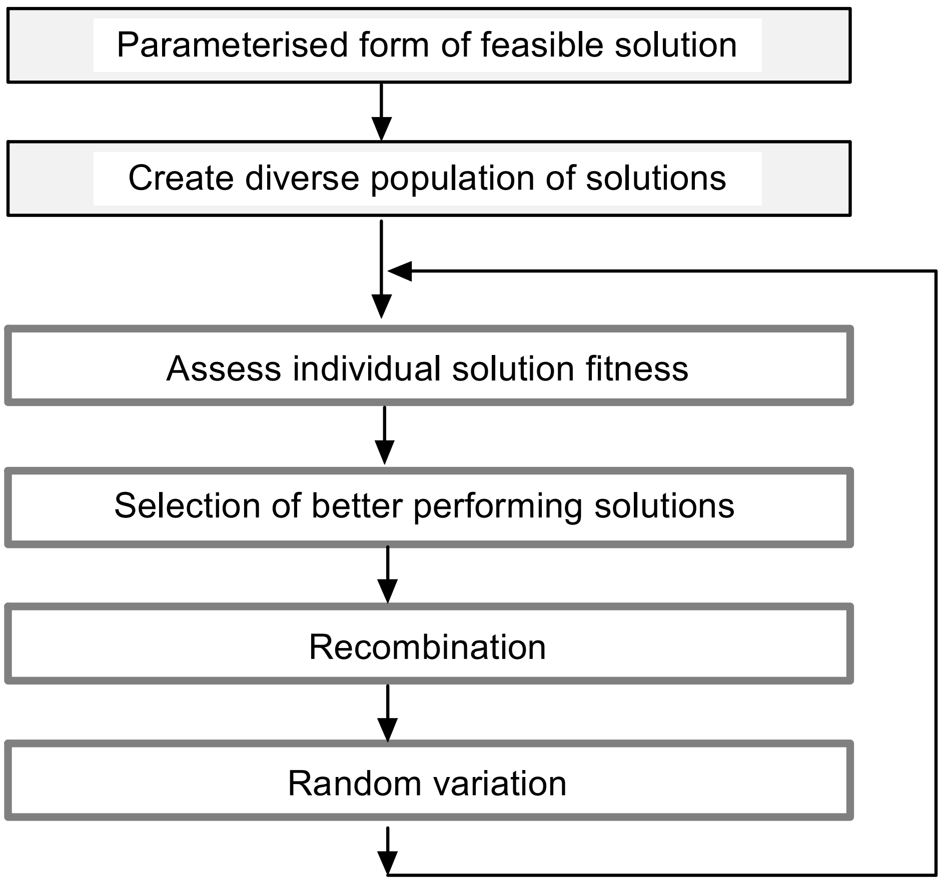


Agent model over time horizon

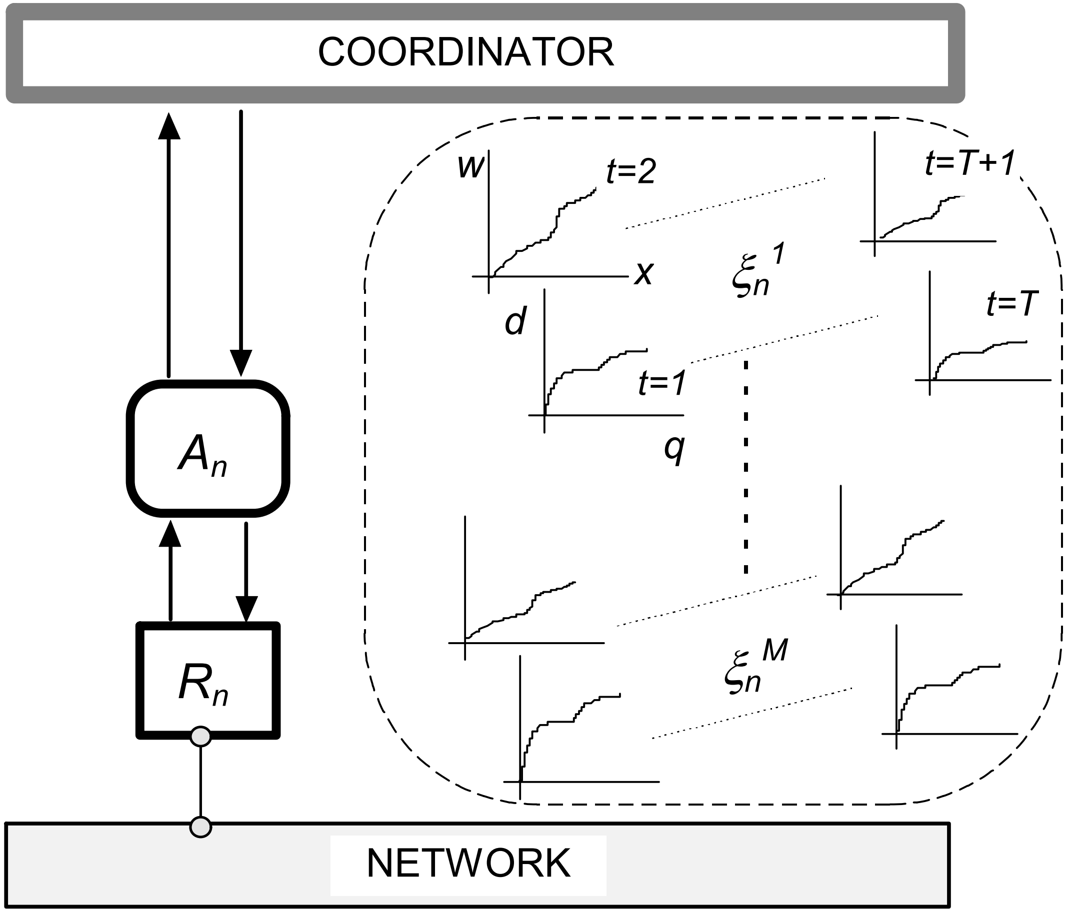


Solving agent/system behaviour: *Evolutionary Programming*

- General process for evolving good solutions to problems

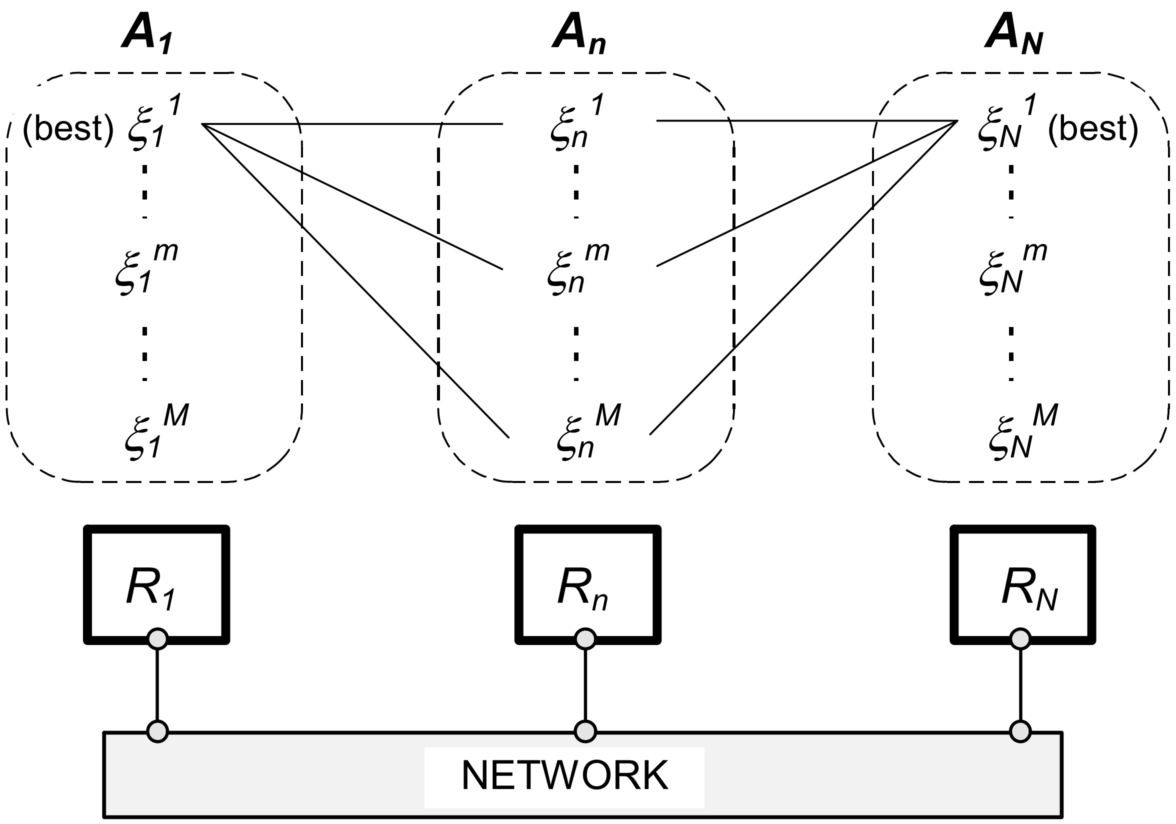


Dual Evolutionary Programming: *evolutionary population*



Dual Evolutionary Programming: *evolving solutions*

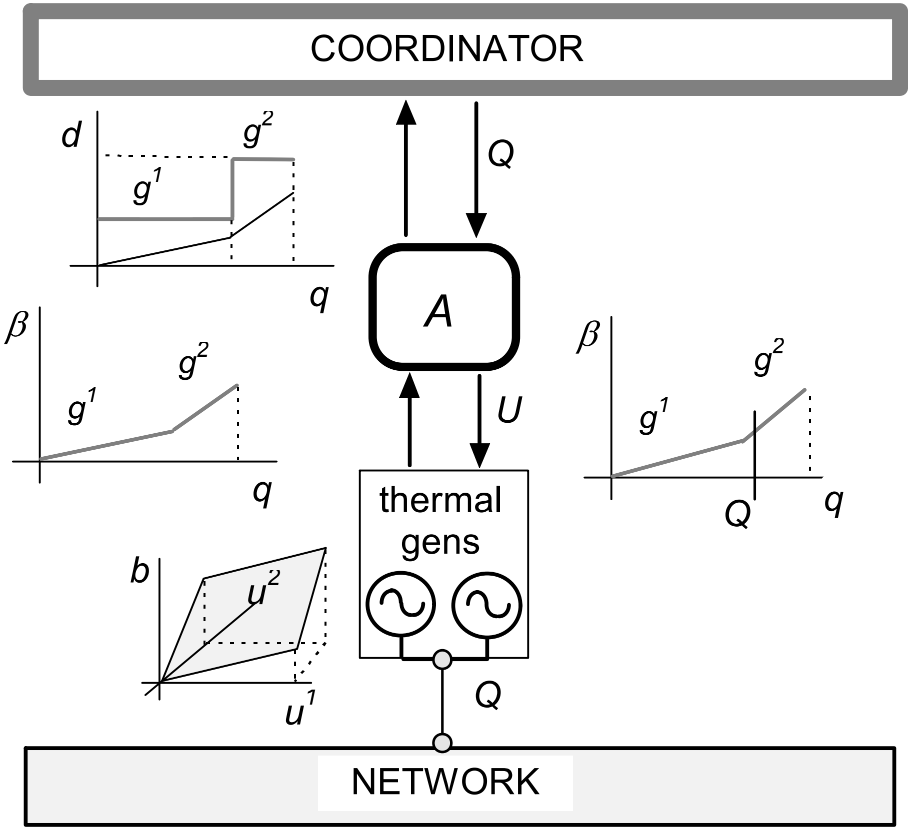
- Solve 'optimal' agent behaviours via repeated power system simulations, and evolution of best agent behaviours



Example: Socially optimal PS coordination

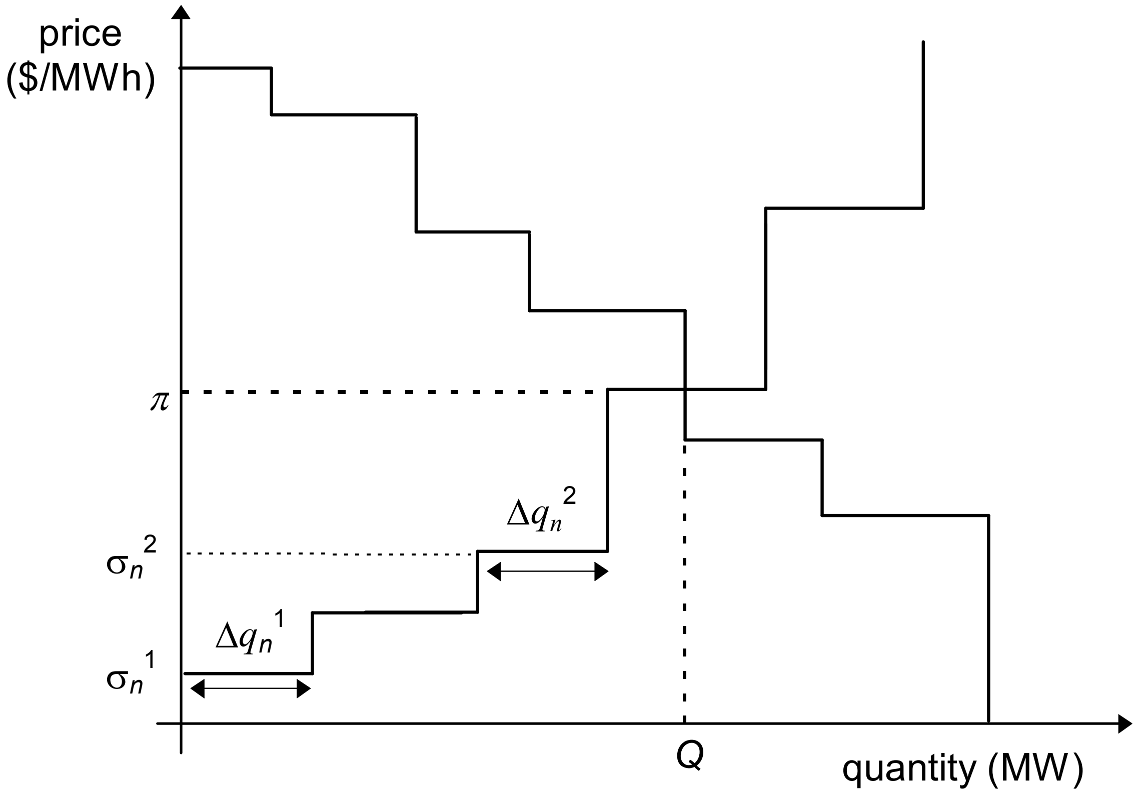
- Agents seeking to achieve system optimal operation

=> Declare true benefit functions to market coordinator



Socially optimal market coordination

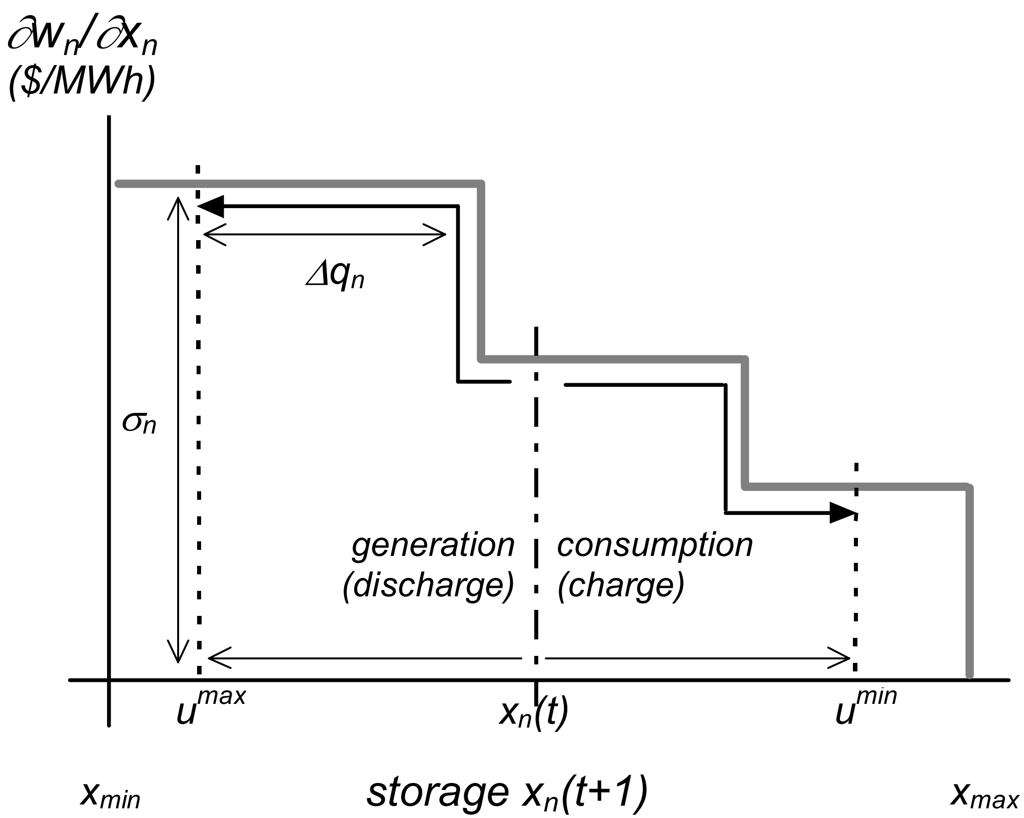
- Agents' benefit functions are dispatched to max. benefits of energy trading



The challenge with resources that have ITLs

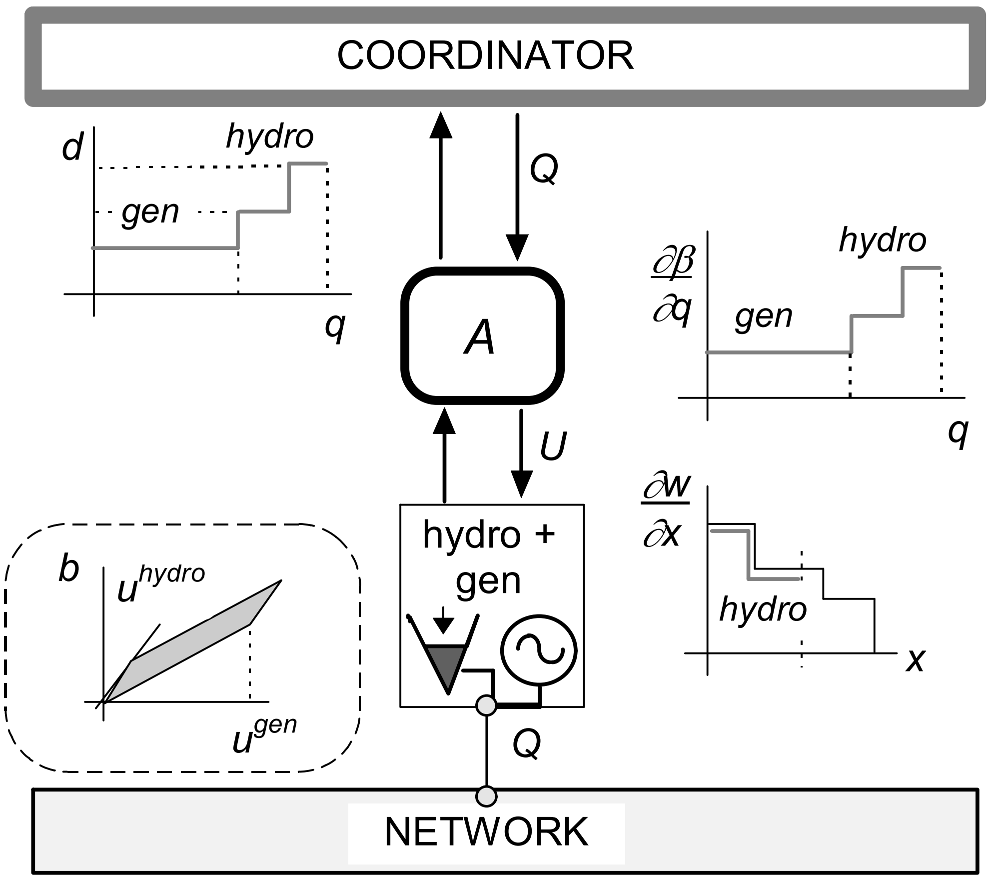
- Benefit function for energy storage depends on other system resources + behaviour over time (eg. daily load profile)

- Example: hydro generating plant with pump storage
  - Value of energy (water) in storage depends on present **+ future** spot market dispatches (typically value declines as more stored energy available)
  - Plant may bid to *buy* as well as offer to *sell*

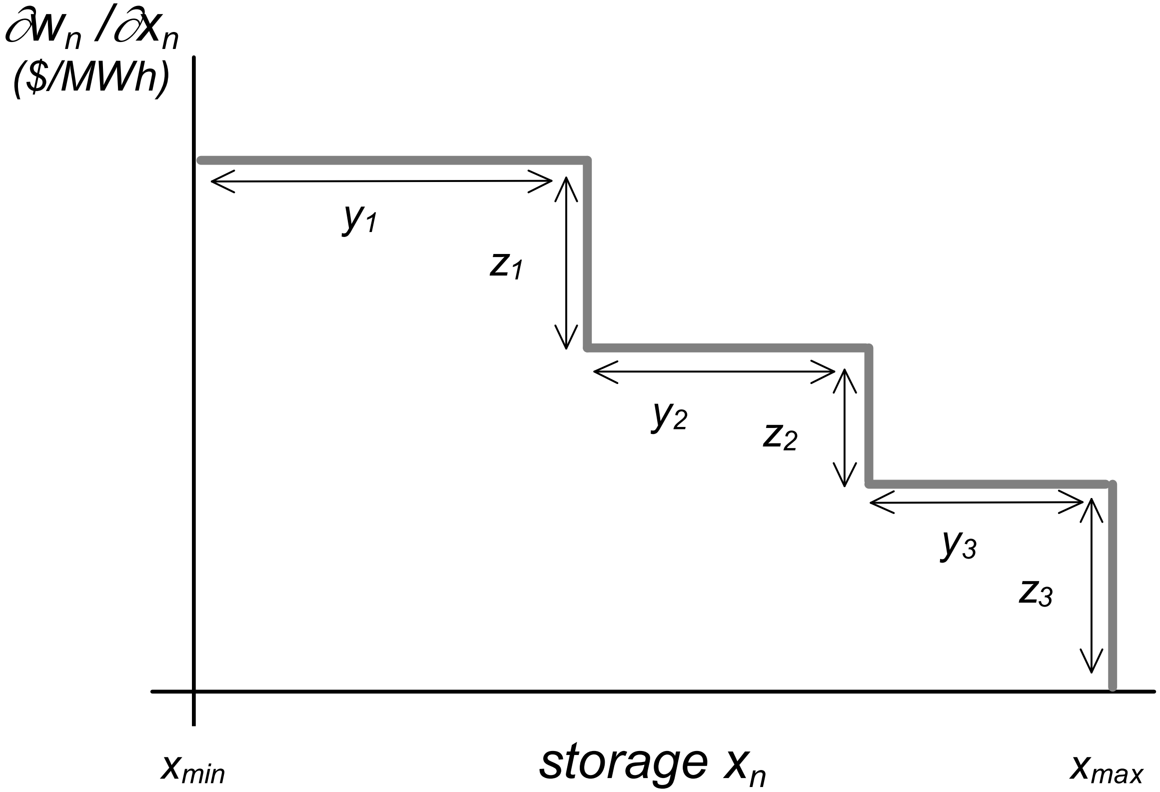


Participant with hydro + thermal plant

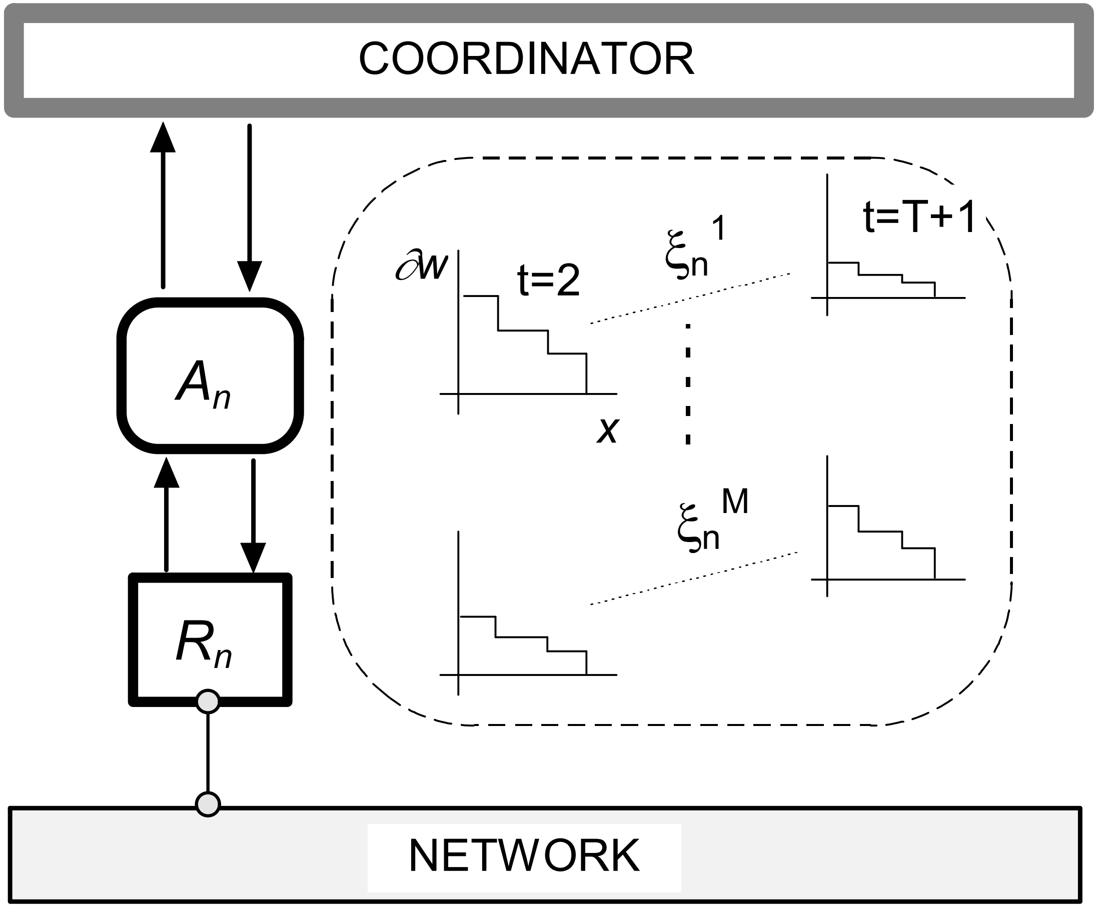
- Submit a market offer that reflects benefits of thermal plant + present value of hydro (wrt current water level)



Parameterised *future value* 'solution' for hydro

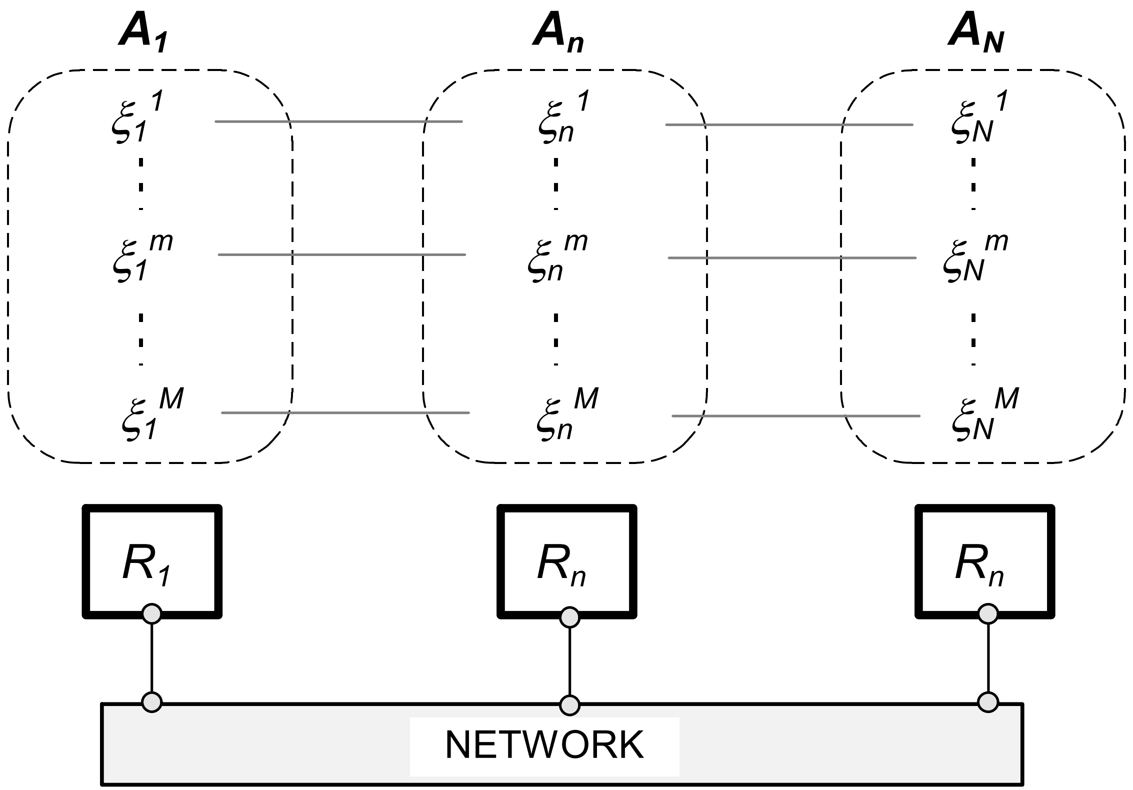


Evolutionary pop. of feasible agent behaviours



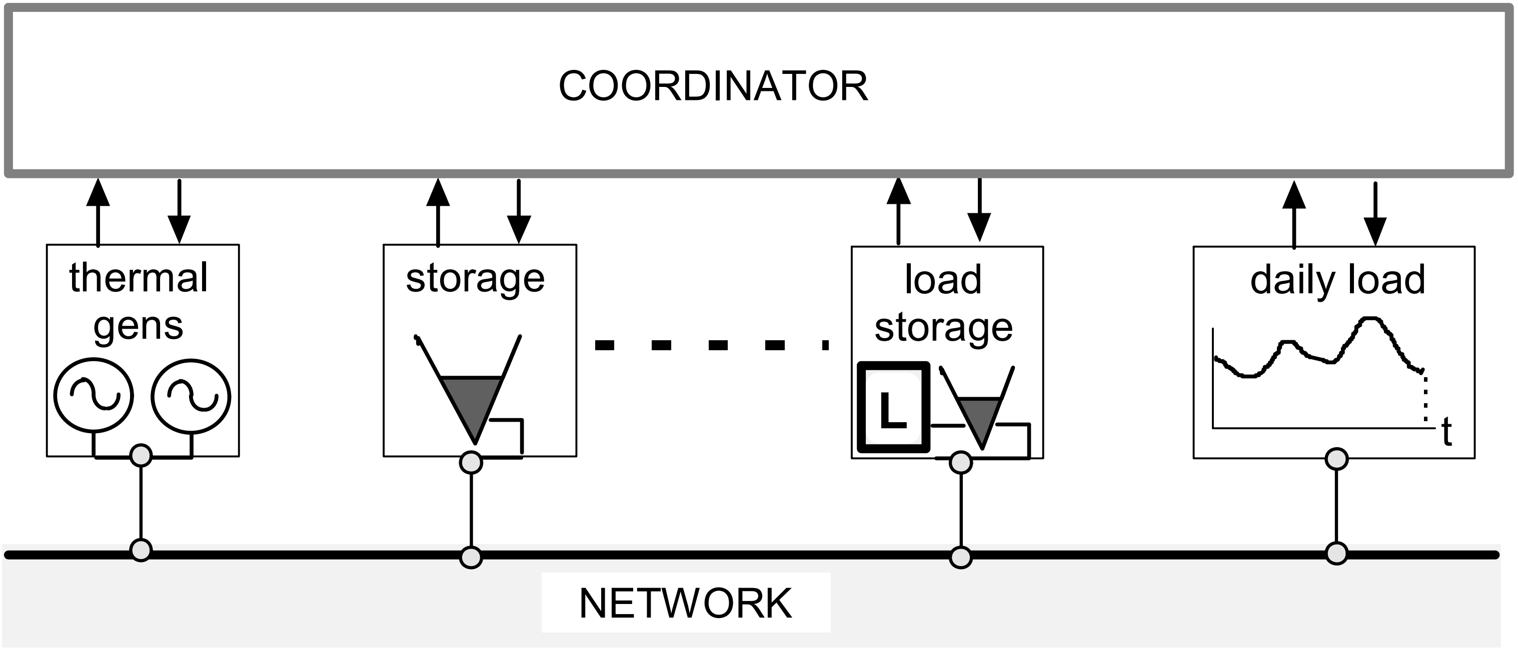
Solve optimal agent behaviour

- Run repeated power system simulations with evolving sets of agent behaviours to max system benefit

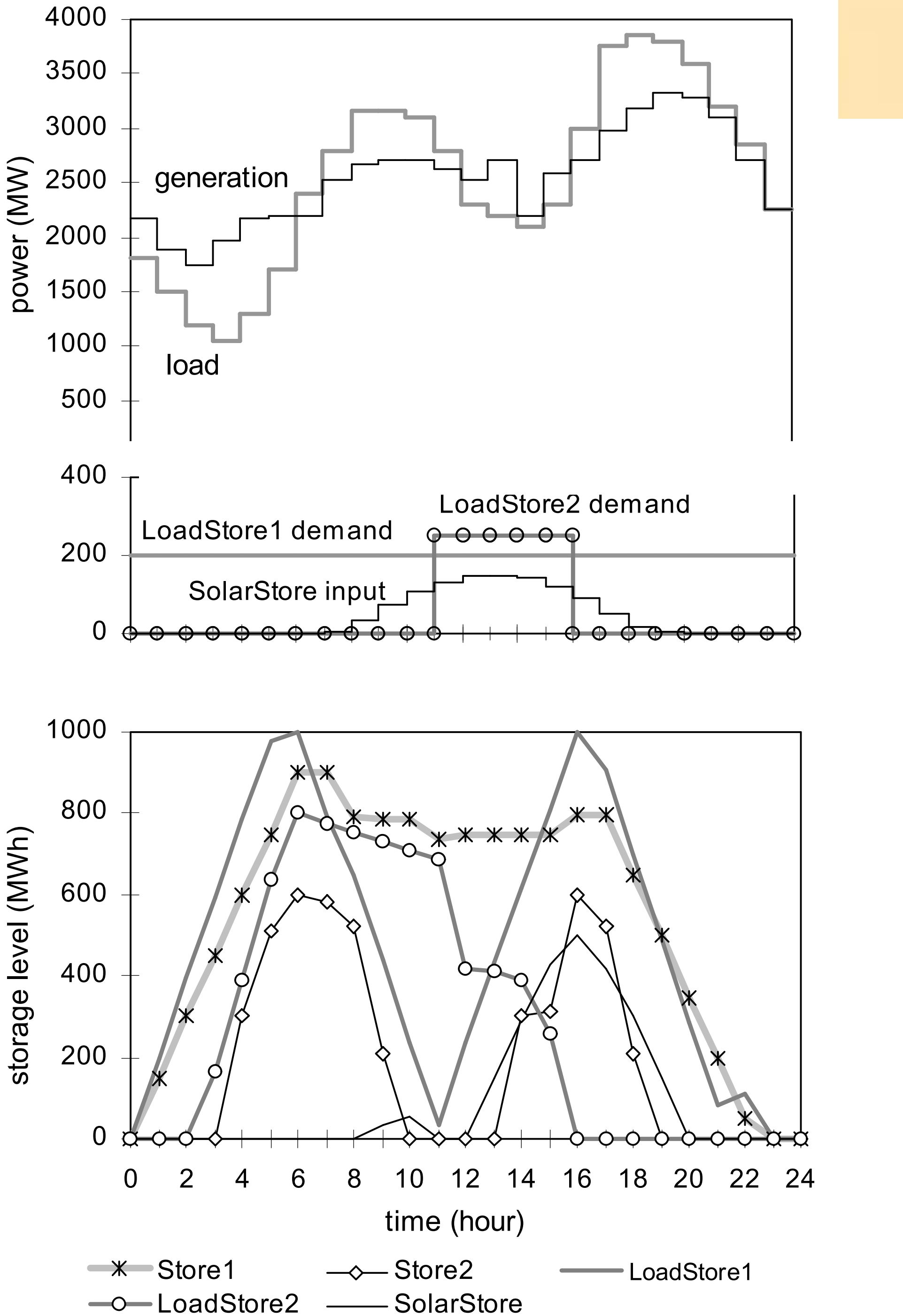


A simple example

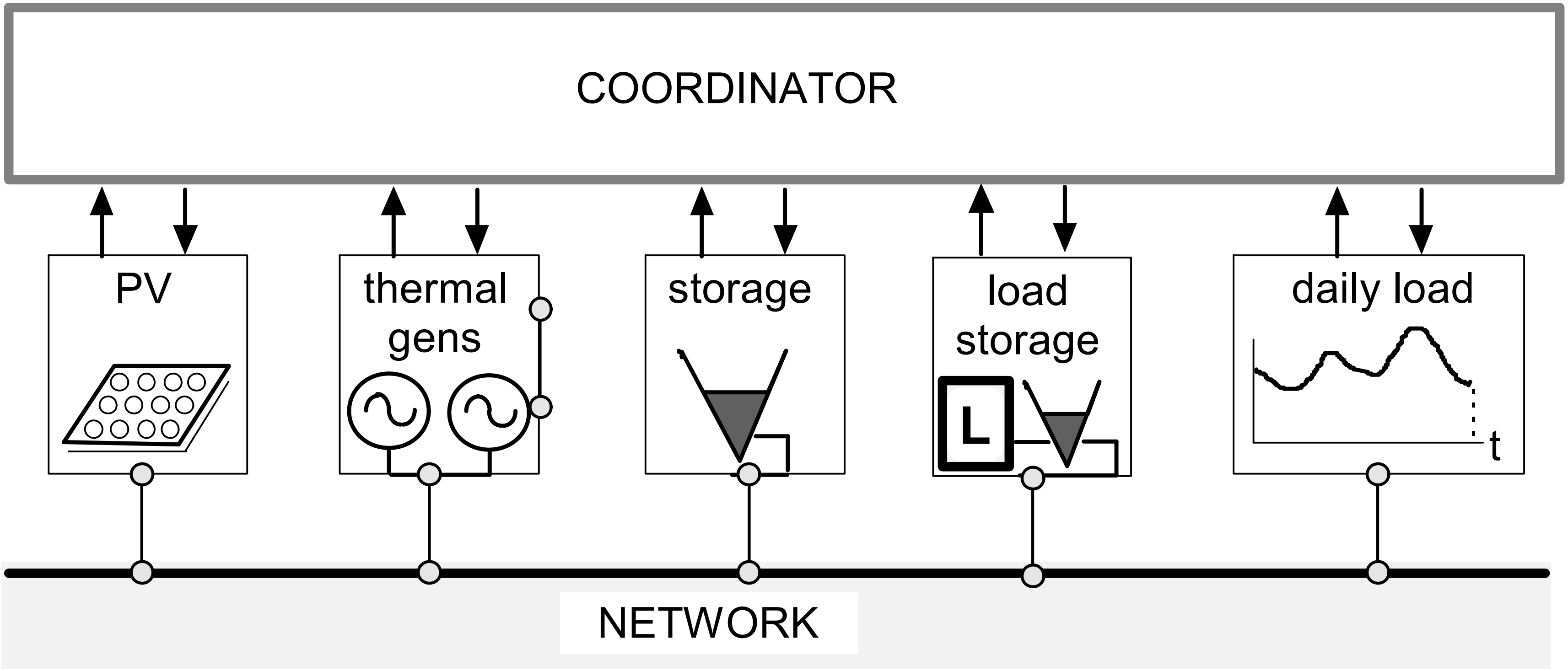
- Five system storages – solar plant with thermal storage, two loads with thermal storage (one high loss), pumped hydro, battery storage



Optimal system operation

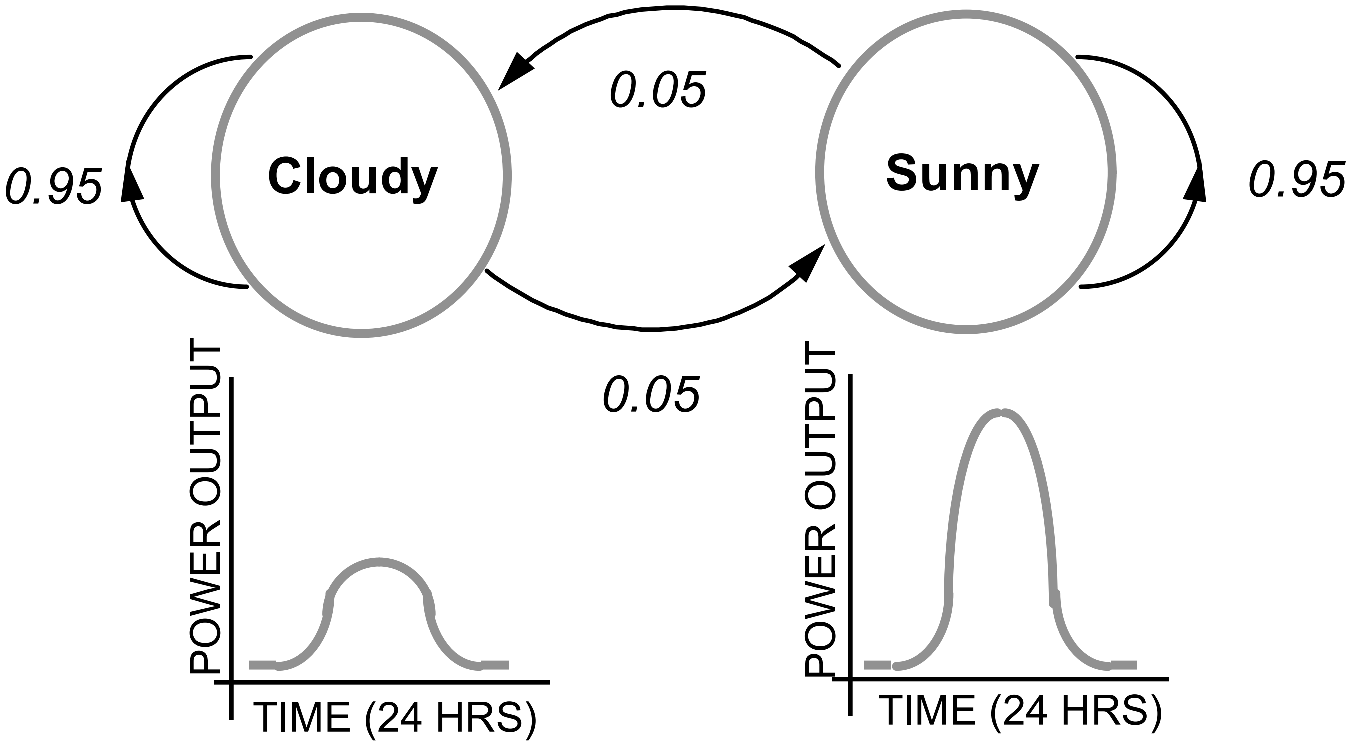


Example: socially optimal PS operation with (aggregated) stochastic PV + load storage



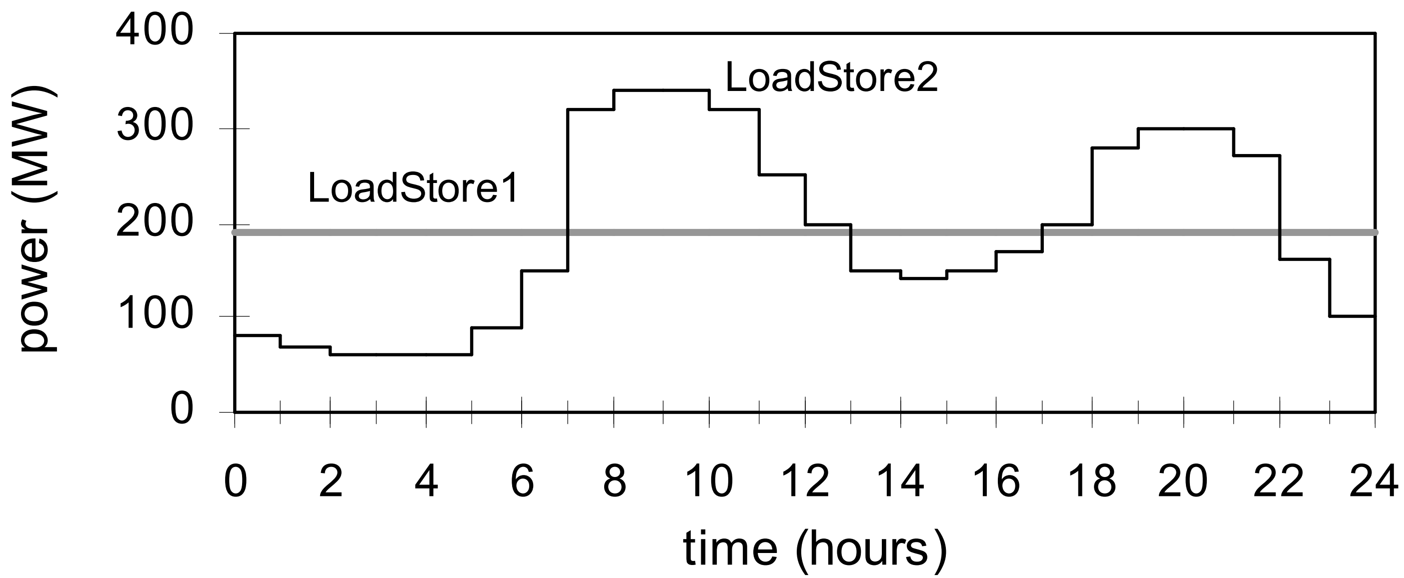
Modelling PV

- Use markov chains linking a number of daily profile ‘states’



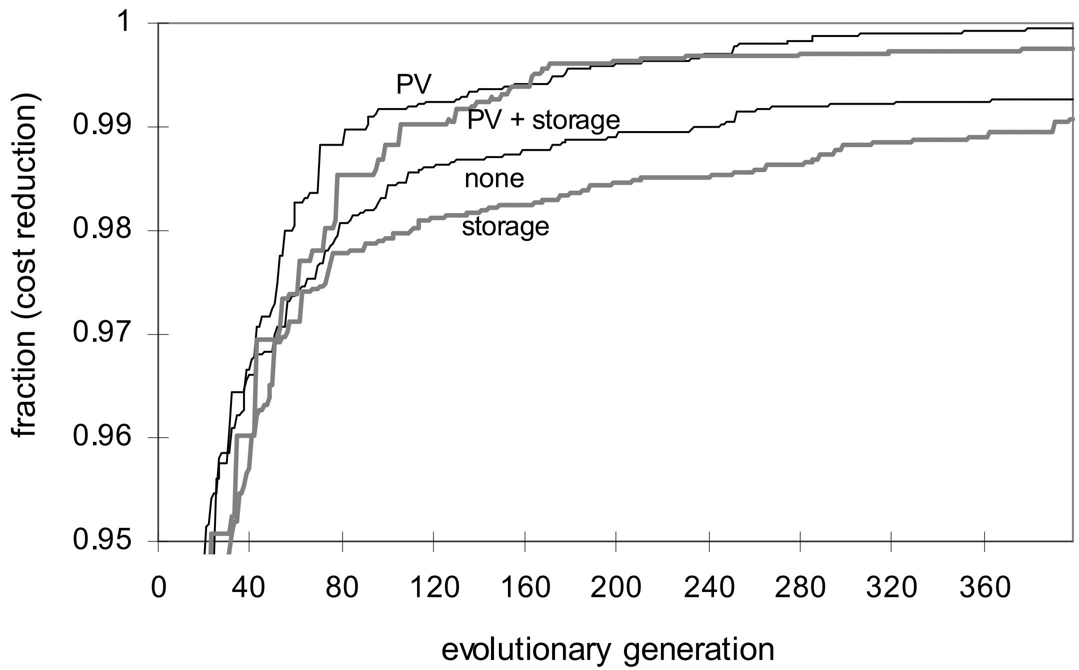
Modelling (aggregated) load storage

- Models can include time varying electrical demand, effective storage capacities, charging rates, charging/discharging losses, leakage

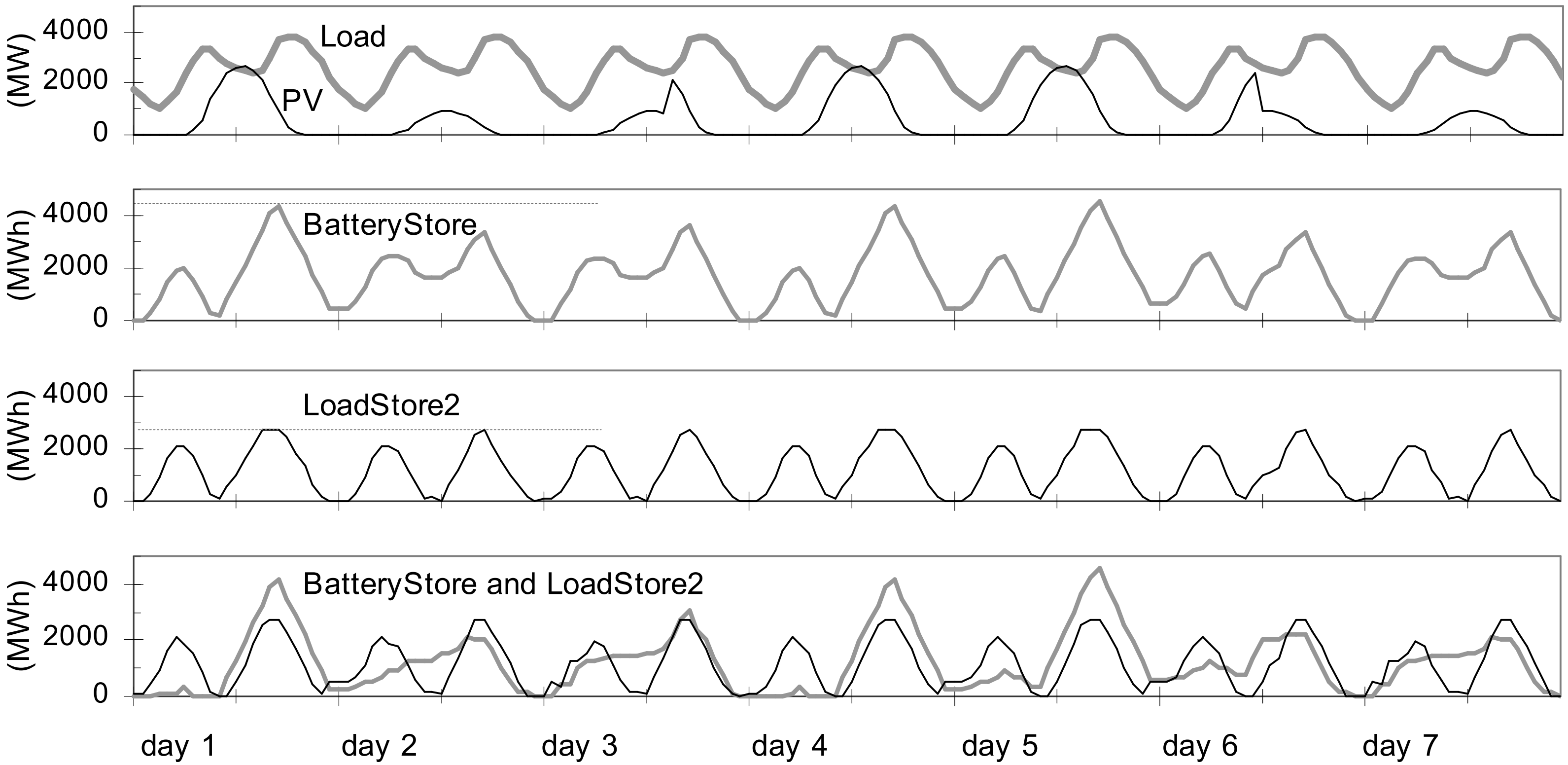


Information scenarios for load agents

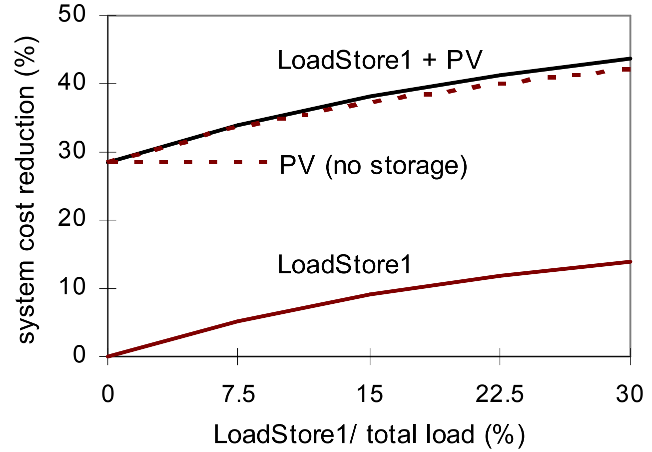
- None
- Knowledge of PV state => evolve two state controller
- Knowledge of *other* storage states => eg. low, medium, high => evolve three state controller
- Knowledge of PV and other storage state => evolve six state controller

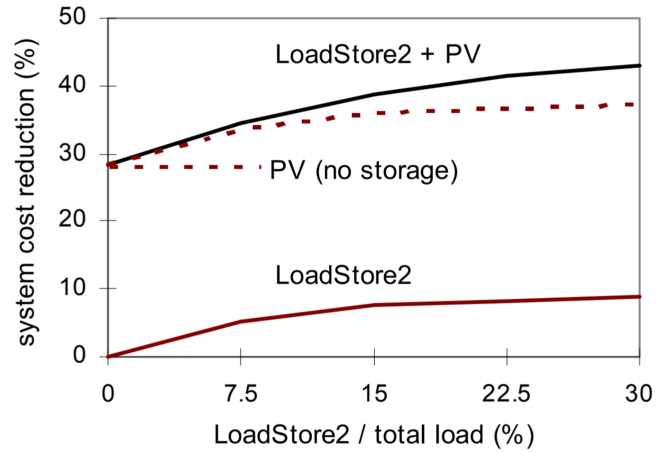


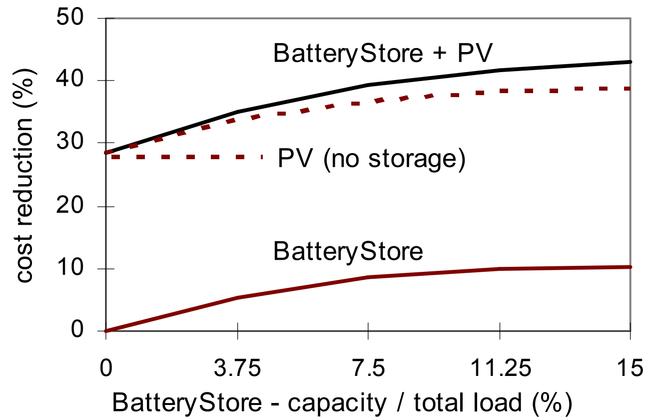
Optimal load operation



Potential synergies between PV + load storage







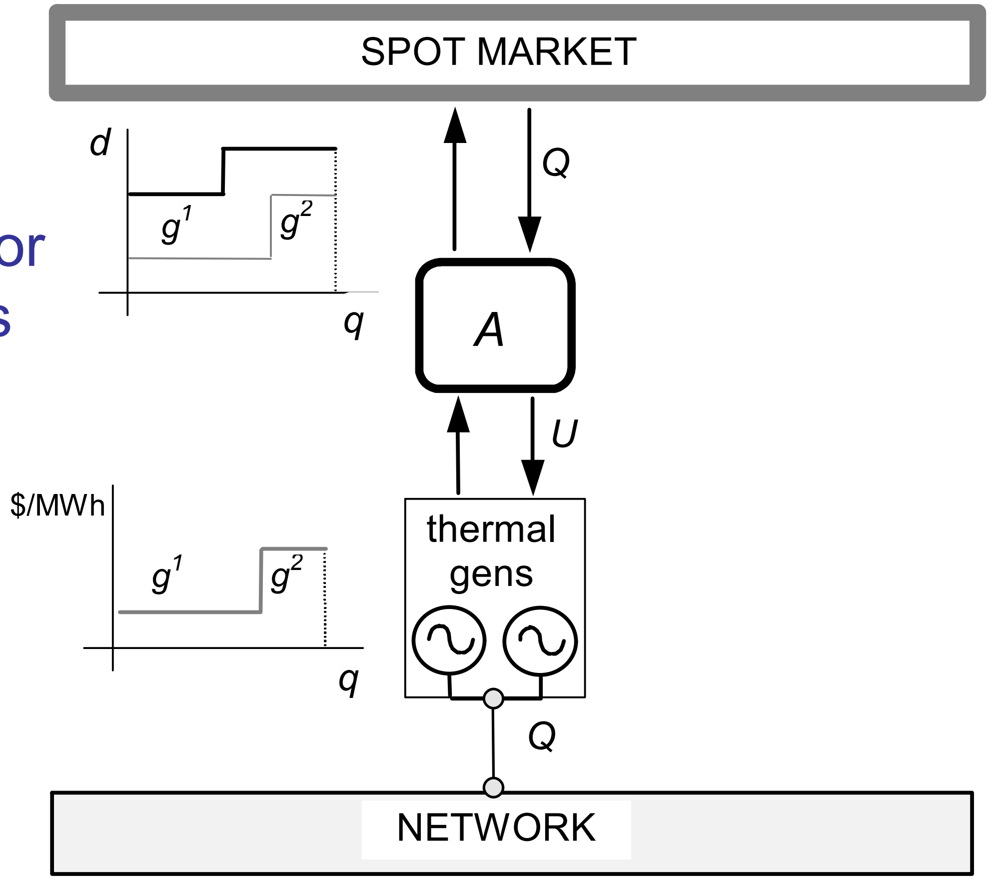
Example: competitive spot markets

- Agents pursue individual profit-maximising objectives. Opportunities for strategic behaviour (ie. not submitting true benefit function) depends on market design + structure

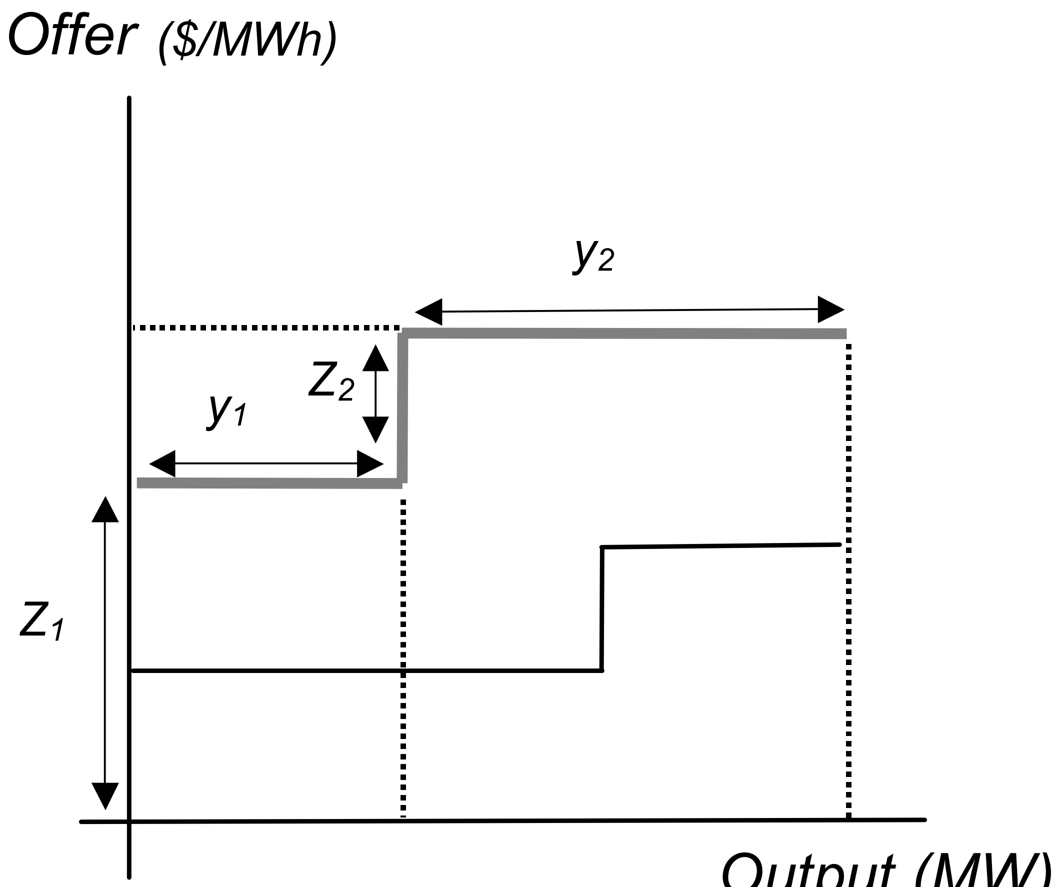
Strategic behaviour within market	***Solution techniques***
None	*Inspection for simple systems,* *LP etc for more complex problems*
Single participant only (or other offers known)	*Inspection for simple systems,* *LP etc for more complex problems*
More than one participant	*Game theoretic analysis for some simple problems (2-3 players)* ***Dual evolutionary programming***

Agent for a participant with 2 thermal generators

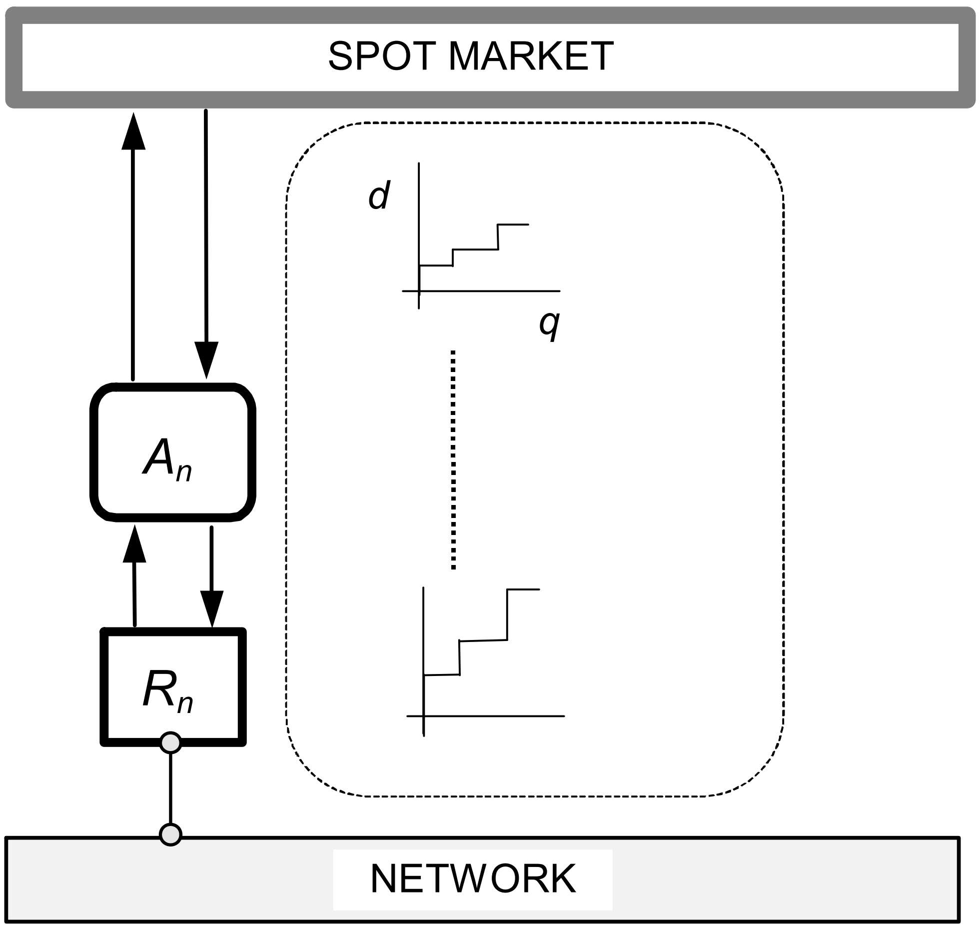
- Agent uses physical plant costs **+ strategic reasoning** to determine market offer
  - Assume linear cost curves for gens, no inter-temporal links



Parameterised market offer 'solution' for an agent

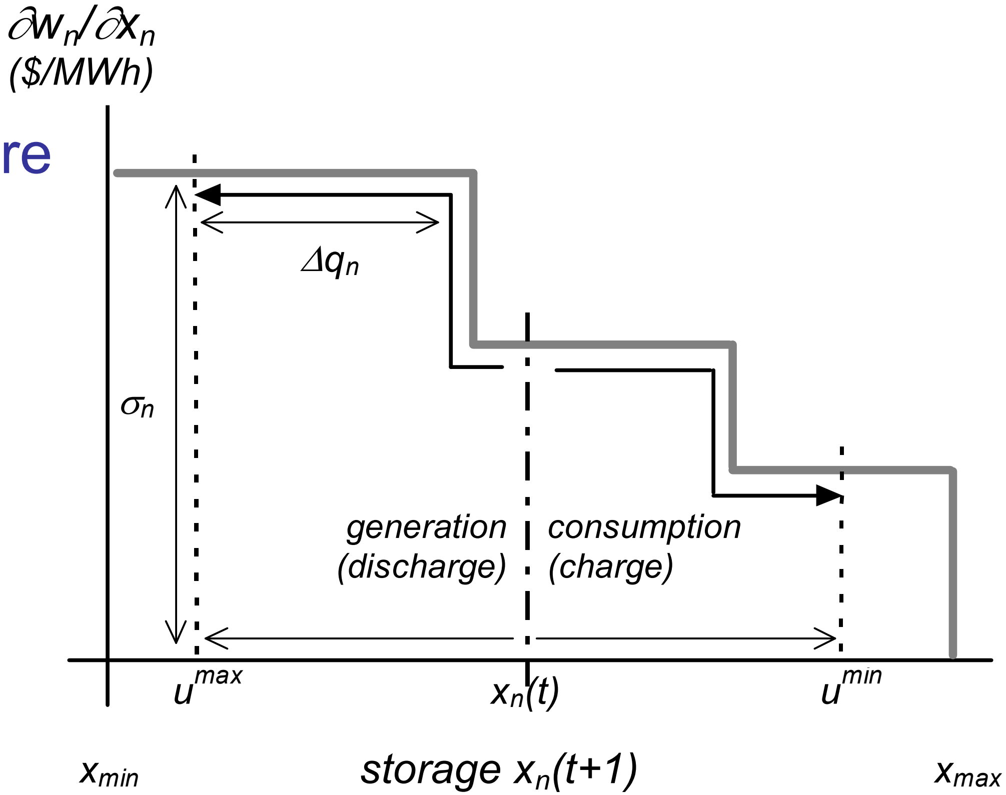


A population of offer 'solutions' for each agent

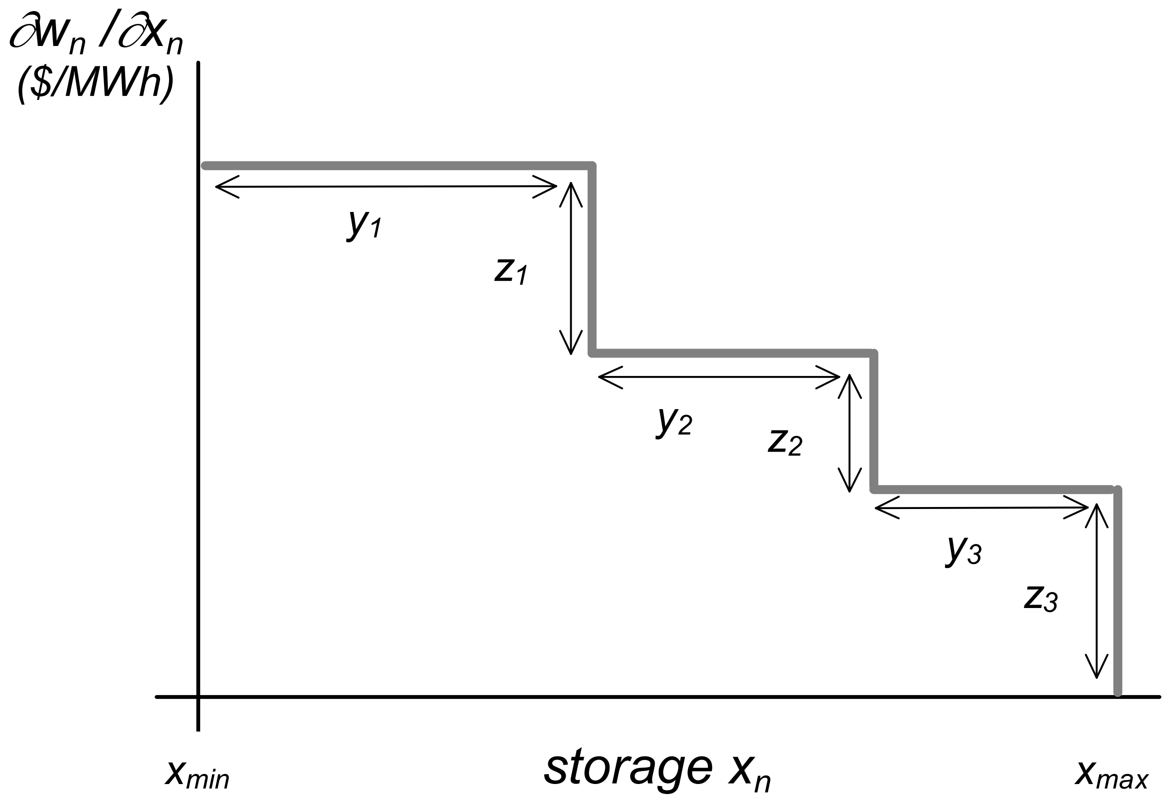


Participants with inter-temporal links

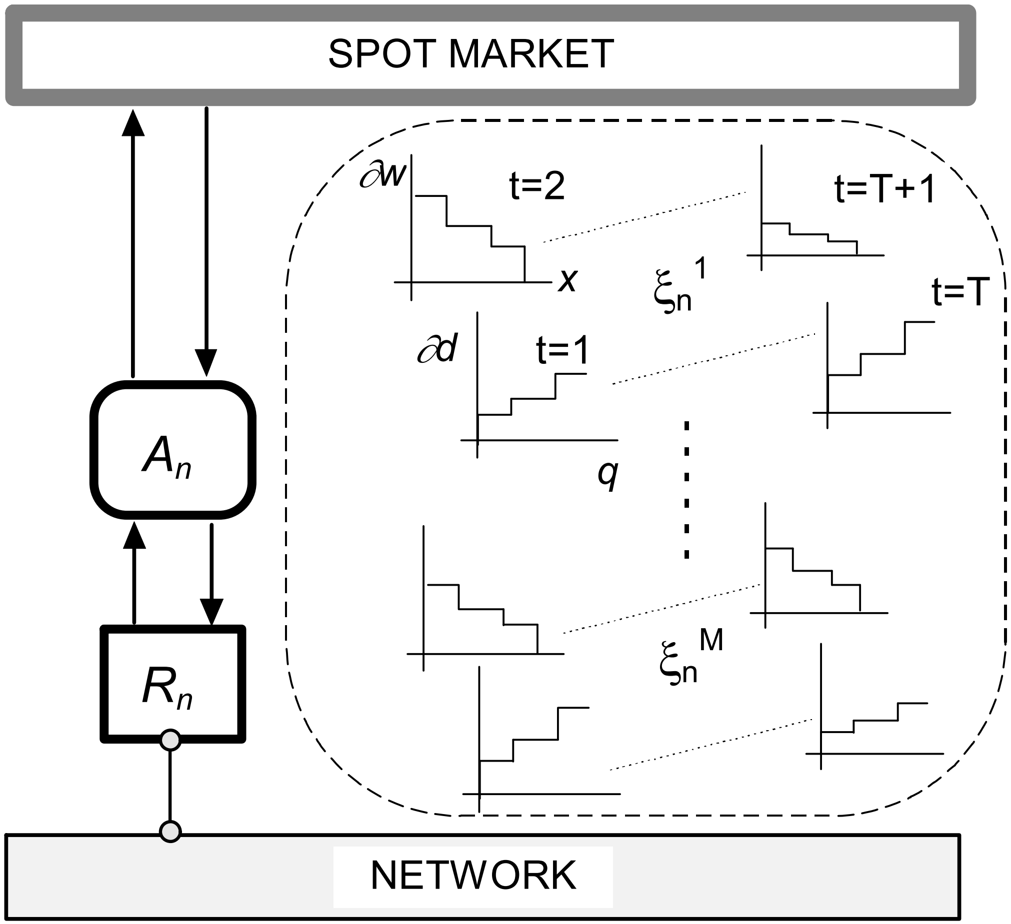
- Example: hydro generating plant with pump storage
  - Value of energy (water) in storage **for participant** depends on present + future spot market dispatches



Parameterised *future value* 'solution' for hydro agent

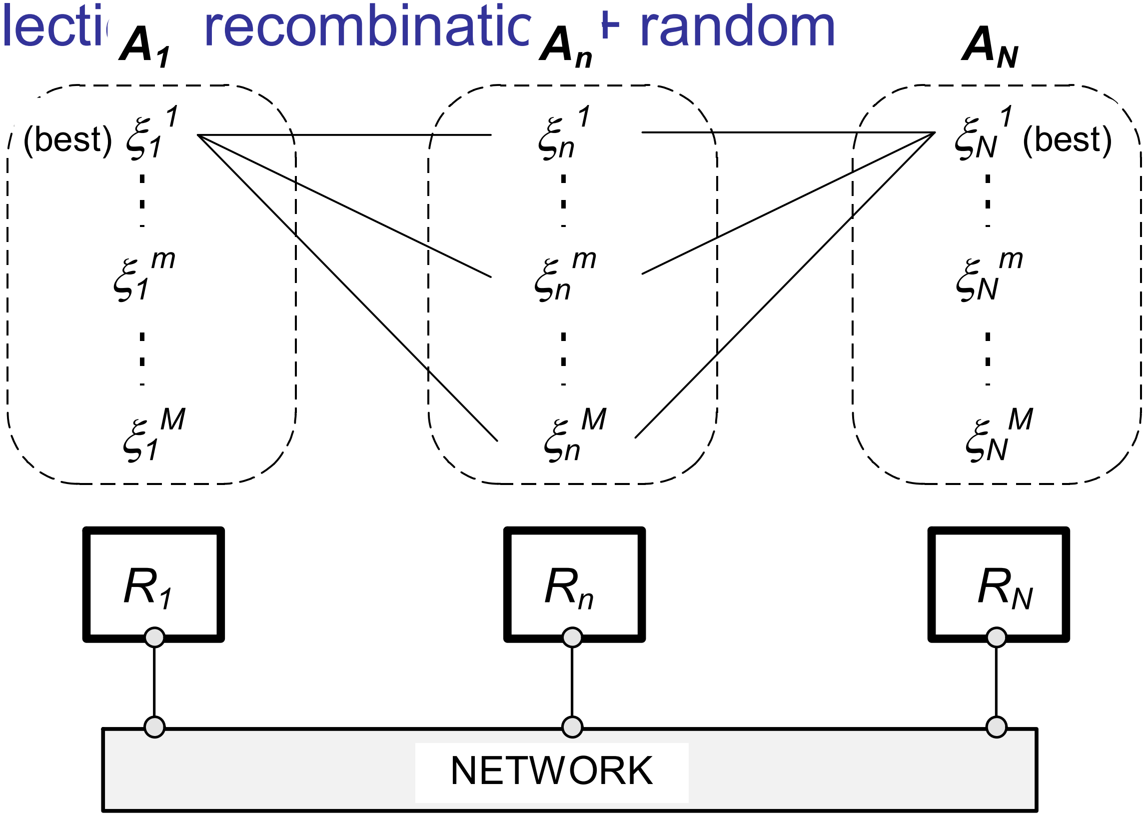


Population of bid/offer solutions for hydro participant



Evolve population of offer 'solutions' for each agent

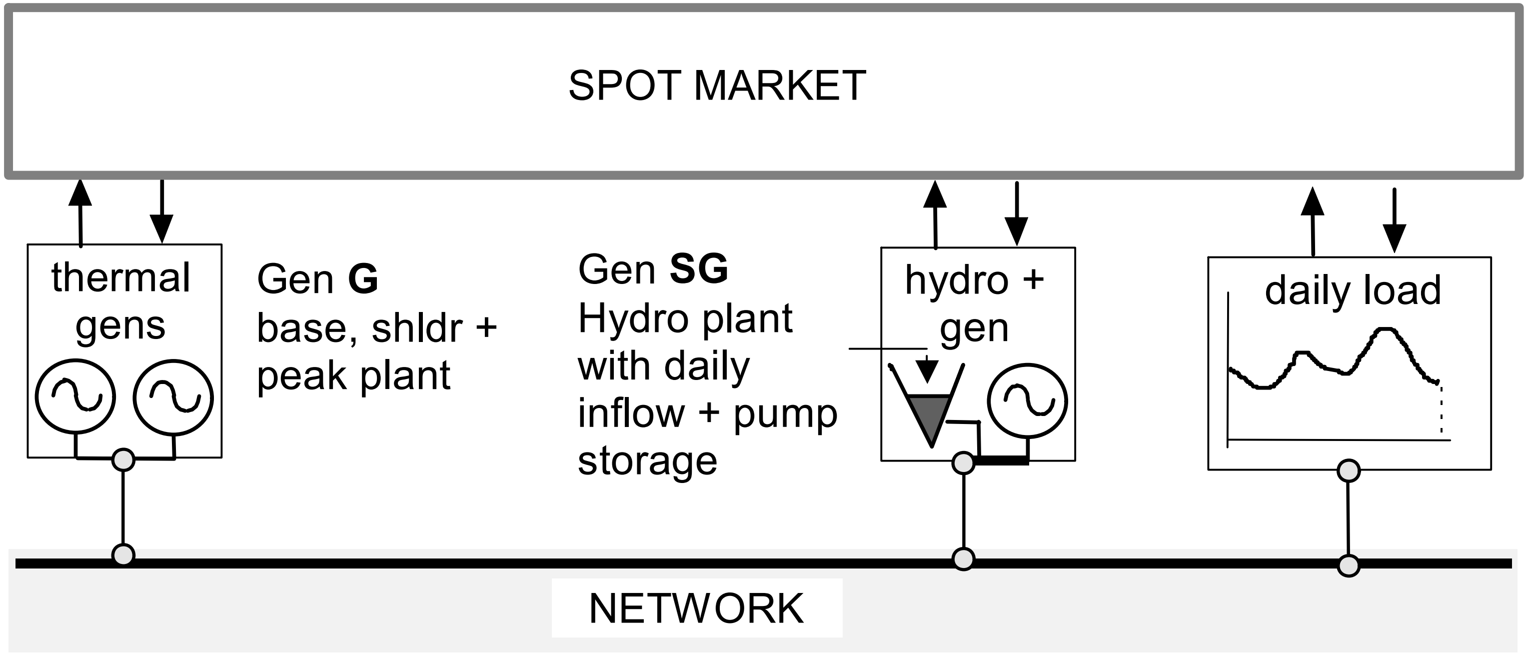
- Progressive tournament – 'all against best'
  - Agent tests and ranks its offers population against 'best' of other agents => selecti recombinatic + random variation
  - Next agent's turn
  - *Tournament continues…*



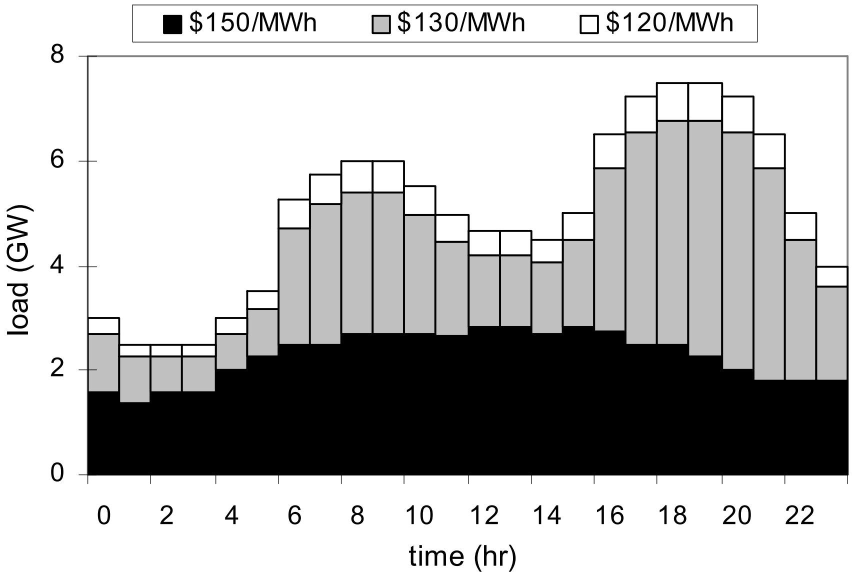
Studies of strategic behaviour in spot markets

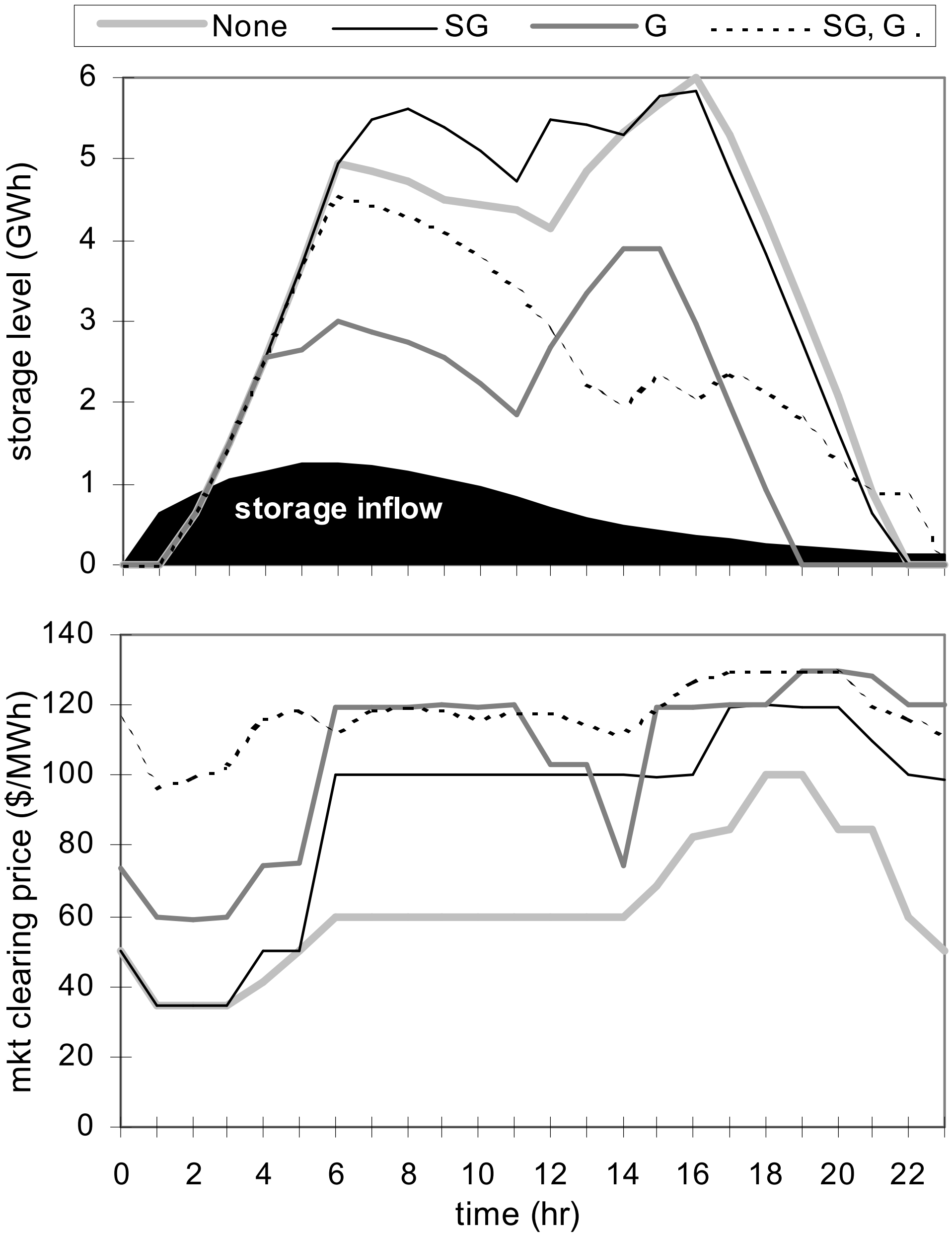
- 2 generator problems
  - EP gives same answers as game theory for simple problems
  - Useful insights with problems where game theory may struggle – eg. if either gen can fully supply load => no Nash equilibrium
  - EP can handle networks, complex plant operation (if you can simulate power system operation, then can use EP)
- Multiple generators including hydro
  - Useful insights into possible participant strategies, mkt impacts
  - Results not tested against other solutions – no tools available..
- Complex industry structures – 5+ generators
  - Useful insights into possible participant strategies, mkt impacts
  - Results not tested against other solutions – no tools available..
- Stochastic generating plant
  - Prelim. work using Markov chains to model stochastic hydro flows

Example: 2 generators including Hydro



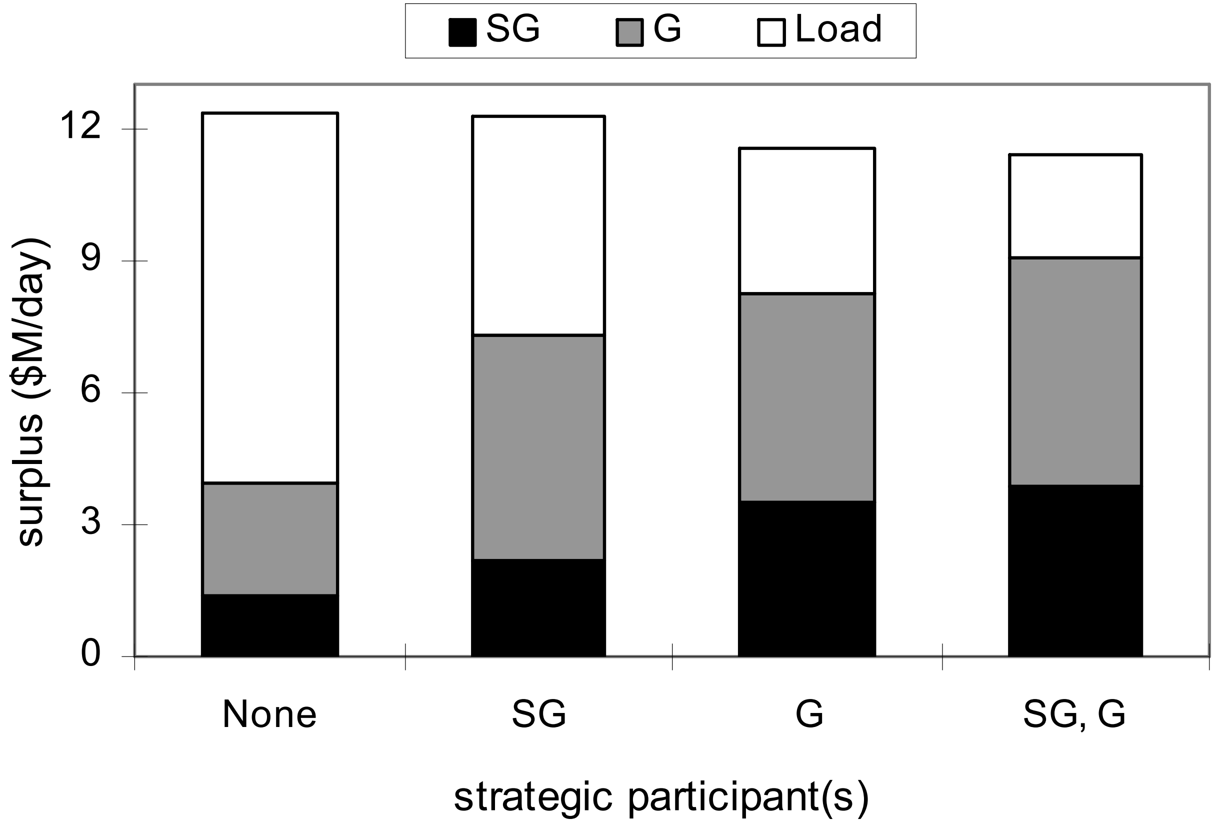
2 + Hydro: EP Results





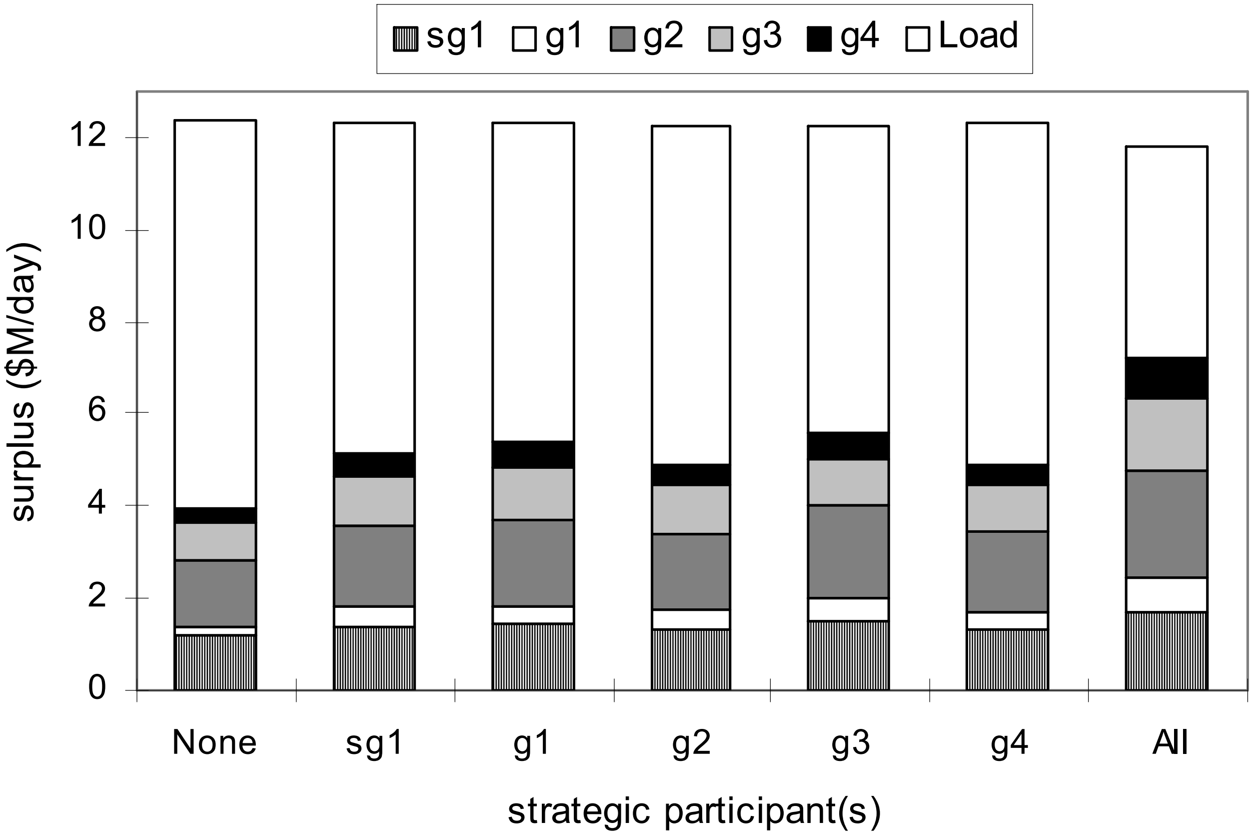
2 + Hydro: EP Results – participant profits

- Surplus (profit) for participants with none, either and both undertaking strategic behaviour



Example: EP Results – 5 generators including hydro

- Surplus (profit) for participants with none, one only and all using strategic behaviour



Summary - potential value of DEP

- Can have complex, realistic
  - resource models – if you can simulate operation, you can probably find ‘good’ behaviour using DEP
  - objective functions – risk weighted, individual, aggregated, socially optimal
  - Agents – eg. Contract positions, etc
  - Complex information scenarios
  - Stochastic resources (markov chains + longer simulations)
- However
  - Computational burden can expand rapidly, particularly with stochastic resources, multiple controller states

Next steps

- ARC funded project – AGSM and Elec. Engineering
  - $250K for three years: 2004-7
  - Will explore analytical and EP tools for understanding participant behaviour in spot + derivative electricity markets

- **CEEM**
  - DEP tools for exploring market design + structure
  - Comparison / validation of EP with Exptl Economics findings
  - Agent support for experimental subjects with complex market designs + structures

For more information…..

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