Synchronization Games in P2P Energy Trading

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Introduction

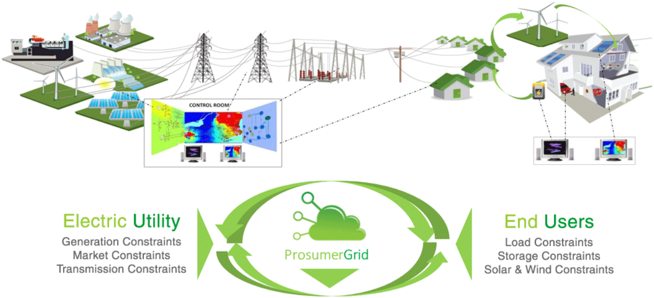
- Renewable energy sources are on the rise
- Topology of the power grid is changing
  - from a centralized system to a decentralized one
  - owner of the grid isn't the only energy producer any more
  - peer-to-peer energy trading
- Integration is challenging
  - since the grid wasn't designed for it

Our contributions

- Introduce the concept of a synchronization game
- Show how selfish prosumers can utilize this concept
- Develop and simulate a model of synchronization games
- Propose methods to tackle this issue

Conflicting Interests

- Network operator vs. prosumers



Source: https://goo.gl/nrXtSH

Conflicting Interests

- Trading layer vs. network layer

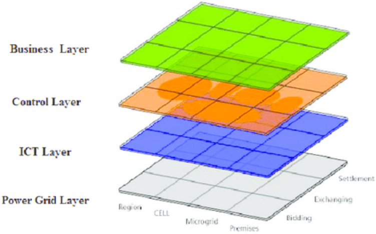


Table 1. Components of Each Layer in the Four-Layer Architecture Model of P2P Energy Trading

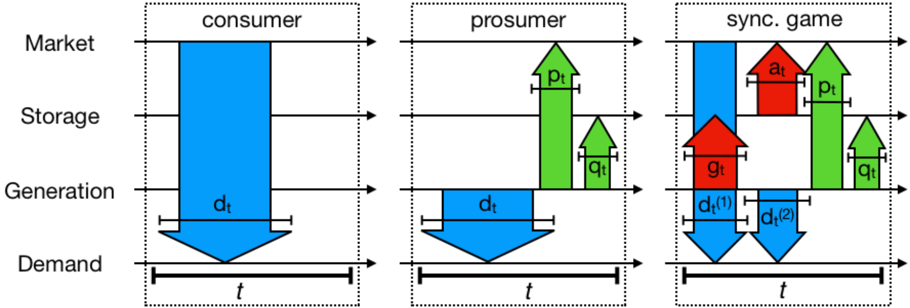
Layers	Components
Power Grid Layer	Existing power grid with DGs, flexible loads, storage, EVs, etc
ICT Layer	Communication network and devices, data storage, information flow, etc
Control Layer	Monitoring and control system owned by SO and DNOs, control functions, etc
Business Layer	Participants in local markets, market authorities, trading platforms, etc

Source: https://goo.gl/4so7gZ

Synchronization Games

- Timing is important in energy network management
- Network operators are constantly balancing to keep the network stable
- Prosumers are able to synchronize their actions with each other in order to drive the price up
  - by creating "artificial demand"
  - which forces the network operator to activate backup reserves
  - and increases the network operator's price
  - which then allows the prosumers to sell at higher prices
- Synchronized behaviour corresponds to a Nash Equilibrium

Synchronization Game Example



Repeated Synchronization Games

- Playing only one synchronization game may not be profitable
  - because it does not necessarily mean that the network operator increases the energy price
- But playing it for multiple rounds is
- The prosumer has to keep the losses from purchasing energy minimal
  - by decreasing the amount of purchased energy
- The amount of purchased energy is inversely proportional to the increase of the operator's price
- Success of synchronization depends on the synchronization accuracy of the prosumers

Model

- Consider a microgrid $\mathcal{M}$ with N agents
  - consumers
  - prosumers
    - using Q-learning to maximize profits
- Agents can perform one action during a discrete time interval t_n
- Microgrid is also connected to a network operator
  - balances the system
  - adjusts the price s_t according to the demand

Q-learning

- Reinforcement learning algorithm
- Model free
- Maximizes reward over all following steps
- States and actions are stored with their respective Q-values
  - Q-values represent the "quality" for an action for a given state
  - Q-values get updated each step
    - $Q(s_{t+1}, a_{t+1}) = (1 - \alpha) \cdot Q(s_t, a_t) + \alpha \cdot (r_t + \gamma \cdot maxQ(s_{t+1}, a))$
- Q-learning gained a lot of attention recently due to Deep Q-learning

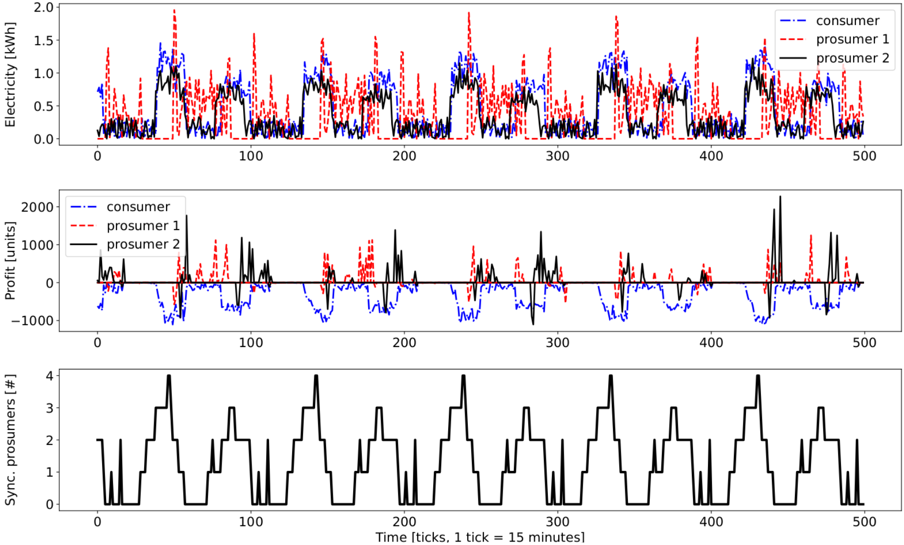
Simulation

- Simulated Microgrid
  - 5 prosumers
  - 20 consumers
  - 1 network operator
- Time interval $t_n = 15$ minutes
- Each agent has a consumption curve with two peaks per day
  - between 6 and 9 AM
  - between 4 and 8 PM
- Each prosumer has a generation curve with one peak per day
  - between 10 AM and 6 PM

Simulation

- Prosumers have two actions to chose from
  - be “friendly”
    - consume generated energy and sell surplus
    - if a deal is successful the price gets increased by 10%
    - if the price appears too high (bigger than the one from the network operator) the price gets decreased by 10%
  - play a synchronization game
    - neither earn nor lose money
    - but the demand gets artificially increased
    - network operator increases the price

Results



Electricity [kWh]
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
consumer
prosumer 1
prosumer 2
Profit [units]
2000
1000
0
−1000
Sync. prosumers [#]
4
3
2
1
Time [ticks, 1 tick = 15 minutes]

Conclusion

What makes synchronization games possible?

- prosumers have more influence on the grid due to their more active role
- successful synchronization can be achieved by installing software

Can we detect synchronization games?

- smart meters play a key role, even though they shortcomings like a low temporal resolution
- monitoring combined with machine learning algorithms for anomaly detection

Can we prevent synchronization games?

- precise metering and real time reporting
- proper incentive mechanisms
- less sensitive energy price