PNRG – A Library for Modeling Variable Structure Energy Grids in Modelica using Energetic Petri Nets

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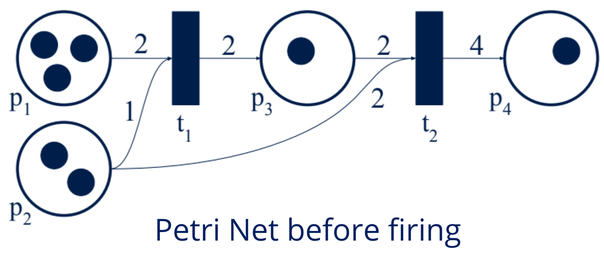
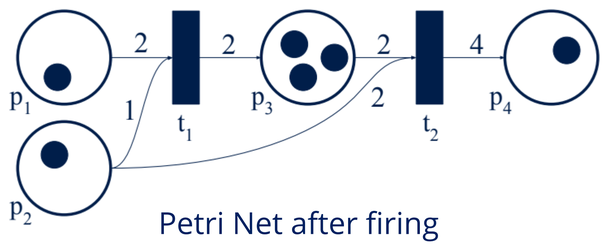
Background

Self-Adaptive Energy Systems

- Increasing share of renewable energy sources in future
  - → Systems need to be flexible
- Sector coupling important
- Increasing complexity
  - → models are important
- Systems with varying structure are challenging to simulate with Modelica [1]



Petri Net before firing



Petri Net after firing

Discrete and Hybrid Petri Nets (PNs) [2]

- Automata theoretical formalism
- Consisting of Places ◯ and Transitions ▮ connected with weighted arcs →w
- Transitions can fire when arc weight ≤ token number in previous place
- will transport tokens then (no conservation law for token number)
- Petri net extensions:
  - Inhibitor and Test arcs [3]
  - Continuous / Hybrid Petri Nets [4]
    - Transitions fire continuously
    - Represent ODE systems with conditions
  - Adaptive Petri Nets [5]
- Petri nets in Modelica implemented with PNlib library [6]

Modeling with Petri Nets

- Discrete PNs can model discrete processes like manufacturing schedules or control mechanisms
- Continuous PNs: arc weights and tokens are real numbers
  - Arc weights are derivative of token number in connected place

→Interprete token as energy and arc weight as power $P = \frac{d}{dt}E = \frac{d}{dt}N = \sum_{i=1}^{N} w_{\mathrm{in},i} - \sum_{j=1}^{M} w_{\mathrm{out},j}$

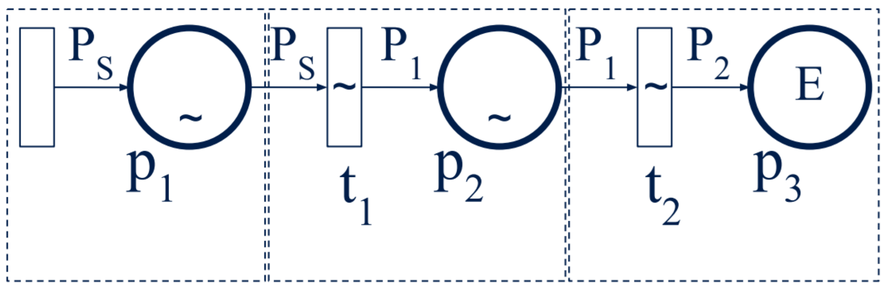
Definition: An **Energetic Petri Nets** is a hybrid Petri Net with inhibitor arcs and:

Energetic Places with: $\sum_{i=1}^{N} w_{\mathrm{in},i} = \sum_{j=1}^{M} w_{\mathrm{out},j}$

Energetic Transitions with: $\forall j : w_{\mathrm{out},j} = f\left(w_{\mathrm{in},1}, \ldots, w_{\mathrm{in},K}\right)$

and: $\sum_{i=1}^{K} w_{\mathrm{in},i} \leq \sum_{j=1}^{L} w_{\mathrm{out},j}$

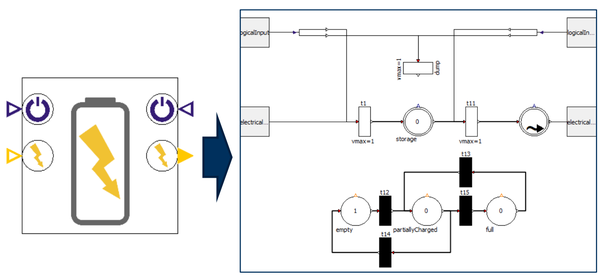
- Energetic places and transitions fullfill conditions of energy transmission
- Needed to decompose Petri net into components



PNRG Library – Petri Net based Renewable Energy Grids

Components

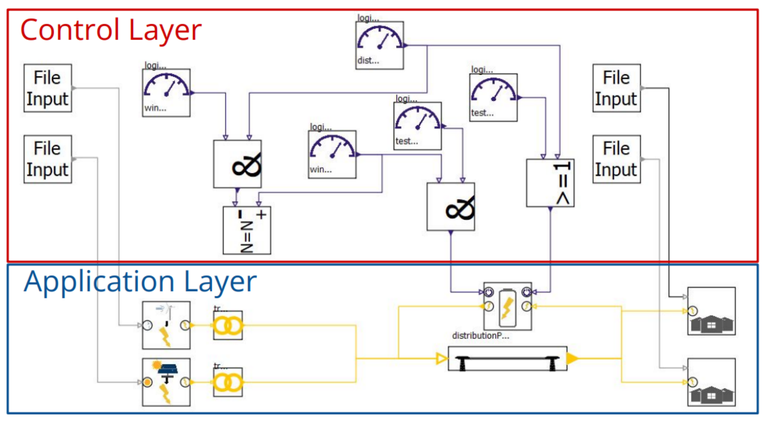
- Components like PV power plants, wind power plant, batteries, transformers or consumers modeled with Petri nets
- Transitions perform energy conversions
- Transitions can be blocked to enable/disable components
- Simplified Model: No Voltages, frequencies or phase angles calculated (for now, possibilities will be investigated)



Example of a Petri net based implementation of a battery

Example

- Grid with wind turbines, PV power plant, battery and consumers
- Battery charging and discharging can be activated
- Number of active wind turbines can be regulated



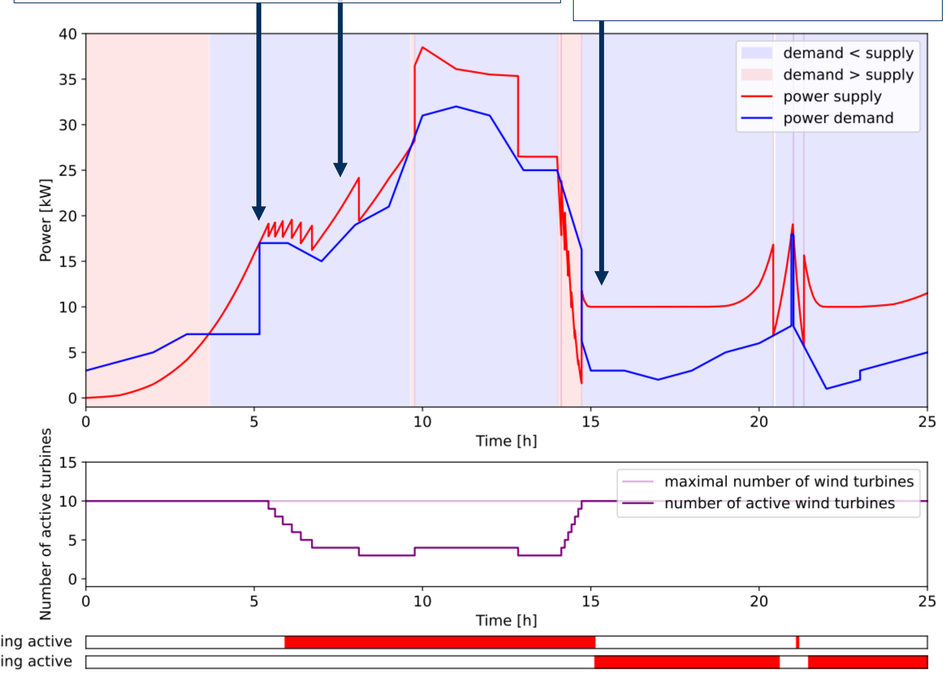
Control Layer

1. Charge battery if possible, deactivate wind turbines only if necessary
2. Discharge battery only if all wind turbines are active but demand is still not covered

Supply increases faster than demand → Active wind turbines reduced

Supply > demand + charging power → Battery charging activated

Supply < demand → Wind turbines reactivated, Battery charging deactivated, discharging activated



→ Works as expected!

Literature: [1] John Tinnerholm (2022). A Composable and Extensible Environment for Equation-based Modeling and Simulation of Variable Structured Systems in Modelica. Linköping UniversityLinköping University, Software and Systems, Facultyof Science Engineering. Licentiate Thesis. ; [2] Carl Adam Petri (1962). Kommunikation mit Automaten. Technische Hochschule Darmstadt. URL: https://edoc.sub.uni-hamburg.de/informatik/volltexte/2011/160/.; [3] Tilak Agerwala (1974). Complete Model for Representing the Coordination of Asynchronous Processes. The Johns Hopkins University, Baltimore, Maryland.; [4] René David and Hassane Alla (1987). "Continuous Petri nets". In: 8th European Workshop on Application and Theory of Petri Nets, Zaragoza, pp. 275–294.; [5] Carl Mai et al. (2018). "Adaptive Petri Nets -A Petri Net Extension for Reconfigurable Structures". In: Proceedings of the Tenth International Conference on Adaptive, Self-Adaptive Systems, and Applications.; [6] Sabrina Proß and Bernhard Bachmann (2012-11). "PNlib – An Advanced Petri Net Library for Hybrid Process Modeling". In: Proceedings of the 9th International MODELICA Conference, September 3-5, 2012, Munich, Germany, pp. 47–56. DOI: 10.3384/ecp1207647.

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