Anylogic simulation conference 2021

Agent-based energy flow simulation of integrated energy systems

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Agenda

- UCL Infrastructure system institute
- Energy system transition overview
- Challenges
- Project objective
- Model details
- Model demonstration
- Future model development
- Reference
- Q&A

UCL Infrastructure system institute

Our mission

- Provide better understanding of how infrastructure enables both service providers and users to innovate to provide better critical services

Our methods

- Interested in Agent-based and object–oriented modeling
- Embrace qualitative data and mixed method approaches

Energy system transition overview

Energy system Decarbonization

- UK set target to reduce emission by 78% by 2035 compared to 1990 levels
- EU Nationally Determined Contribution (NDC) set a long term climate stabilization target that holding global warming at well blow 2 °C
- Energy system decarbonization is an vital part since emission reduction in energy supply sector will dominate up to 2030 [1]

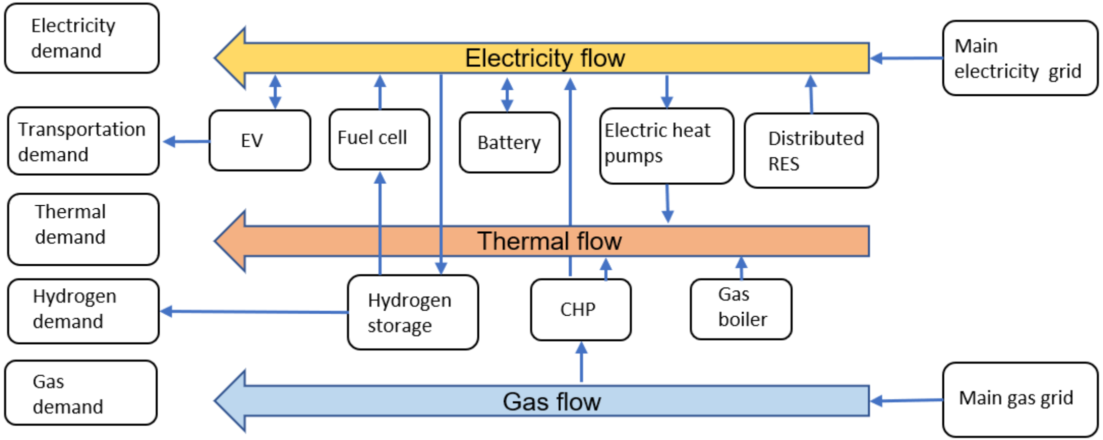
Technology advancements

- Distributed renewable energy generation units (e.g. roof-top PV)
- Tight interactions within energy sub systems through distributed technologies, such as combined heat and power (CHP), heat pump (HP), air conditioning devices
- Tight interactions between energy system and other systems (e.g. fuel chain and transport system) by electric vehicles or hydrogen fueled vehicles

Energy system transition overview(cont'd)

Integrated-energy systems (IES)

- Integration of renewable energy recourses (RES) and transportation sector
- Integration of multiple energy vector (e.g. Electricity, natural gas, and thermal)
- Integration of information communications technology (ICT)



Schematic diagram of IES

Challenges

Challenge 1: combined simulation of multiple energy vectors

- Traditional energy system analysis is conducted on a separated manner, which means each sub-system and planned and optimized individually without considering the interactions between different energy sub-networks. Therefore, a new analyzing methodology is required for future energy system.

Challenge 2: A gap in agent-based modelling application studies in network (regional) level

- Most of studies in ABM application focus on building level systems (HVAC system) and community level systems (micro-grids)
- Other studies in network level limited to application of a particular technology (sensors and communication protocols) and reliability evaluation

Project objectives

Objectives

- Further develop the agent-based modeling methodology for multi-energy networks published in [2]
- Experiment multi-energy flow simulation with real-world case study data

? Why use Anylogic

- Software package dedicated to agent-based modeling
- User-friendly interface
- Easy integration with JAVA package

Model details

Energy flow (Power flow)

- States of energy networks: flows from one node to other nodes in the network
- Results: magnitude and phase angle of voltage at every bus (node), and active and reactive power flowing in each edge.
- Energy flow analysis is important for network extension planning and determine the best operation of existing system

Bus (node) types

- Slack bus

Balance the active and reactive power in the system (source/sink)

- Control bus (PV bus)

Connected with generators

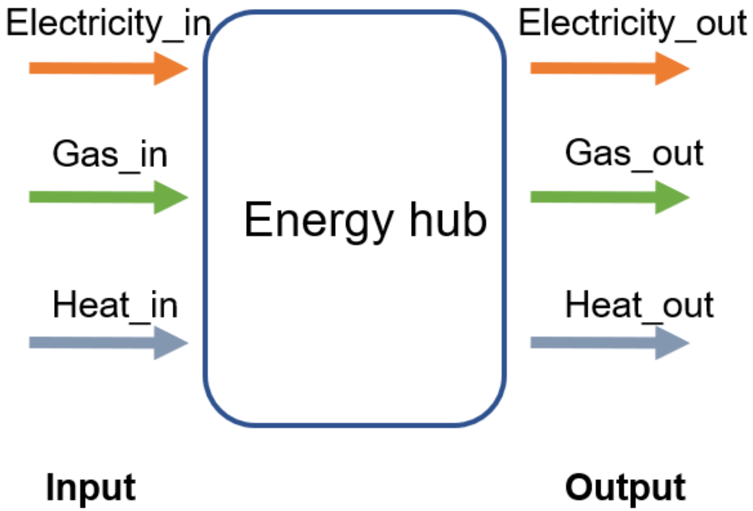
- Load bus (PQ bus)

Connected with loads

Model details (cont'd)

Energy hub (EH) Overview

- Energy hub was introduced by Geidl and Anderson in 2005 [3]
- EH is a mixed energy vector system with three basic features: input and output, conversion, and storage
- The multi-energy networks were modeled as interconnected EHs



Schematic diagram of EH

Model details (cont'd)

Network construction

For each nodes

$$f_i - \sum_{j=0, j \neq i}^{n} f_{ij} = 0 \;\; (eq.1)$$

Flow injection

Branch flows

Conservation laws: for any node in network, the sum of all branch flow must be equal to flow injection

For network

$$\begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix} - \begin{bmatrix} c_{11} & \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ -c_{n1} & \cdots & c_{nn} \end{bmatrix} \begin{bmatrix} e_1 \\ \vdots \\ e_n \end{bmatrix} = 0 \cdots (eq.2)$$

Flow injection at each nodes

Laplacian Matrix or *Kirchhoff Matrix* (For electricity network: *admittance matrix*)

Across variables (For electricity networks: voltages at each node)

Model details (cont'd)

Energy flow analysis

Electricity networks

$$\mathbf{i}_i = \sum_{k=1}^{n} \boldsymbol{y}_{ik}\boldsymbol{v}_k \quad (eq.3)$$

$$S_i^* = \boldsymbol{V}_i \boldsymbol{i}_i^* \rightarrow \boldsymbol{i}_i = \frac{p_i - jq_i}{\boldsymbol{V}_i^*} \quad (\text{eq}.4)$$

Substituing $\boldsymbol{i}_i$ into eq.3

$$\boldsymbol{V}_i = \frac{1}{\boldsymbol{y}_{ii}}\left(\frac{p_i - jq_i}{\boldsymbol{V}_i^*} - \sum_{k=1,k\neq i}^{n} \boldsymbol{y}_{ik}\boldsymbol{i}_i\right) \quad (eq.5)$$

Complex voltage value at bus *i*

Pipeline networks [3]

$$F_{mn} = k_{mn}\delta_{mn}\sqrt{\delta_{mn}(p_m^2 - p_n^2)} \quad (eq.6)$$

p_m: Upstream pressure

p_n: Downstream pressure

k_{mn}: Properties of pipeline and the fluid

Model details (cont'd)

Energy flow analysis

Electricity networks

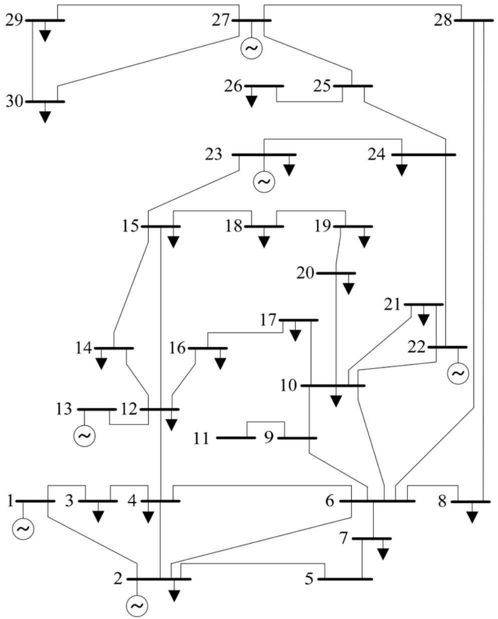
- Implemented with Gauss-Seidel algorithm
- Computed by agents in decentralized manner. Each agent compute the complex voltage value $\boldsymbol{V}_i$ at *i*-th node and then it is used immediately as actual value for calculating new voltage value $\boldsymbol{V}_{i+1}$ at next agent
- Aggregate of all agents emerges the behavior of the network

Pipeline networks

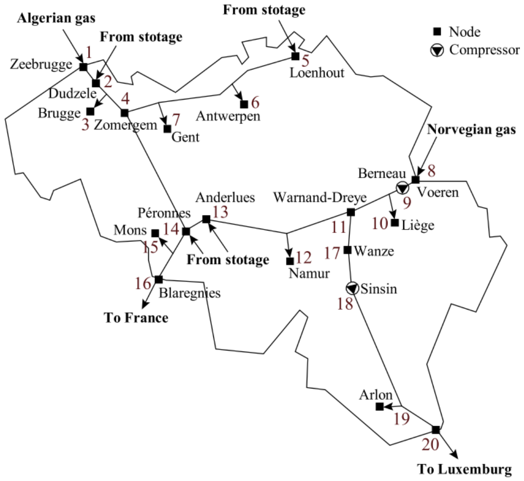
- Mimic the electric power-flow method and change the value of potential at each node
- Simpler than electricity network: all variables are real and only slack type generator

Model details (Cont’d)

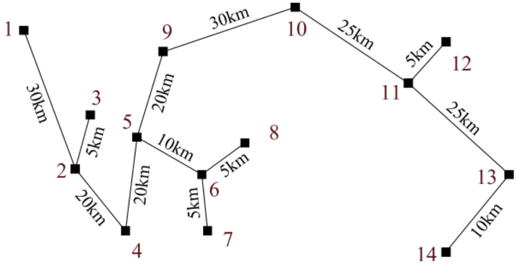
Energy network case study (data obtained from published articles)



Electricity 30 nodes network [4]



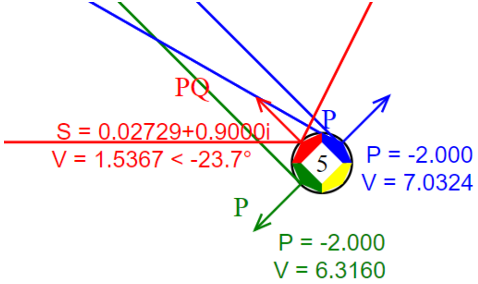
Gas 20 nodes network [5]



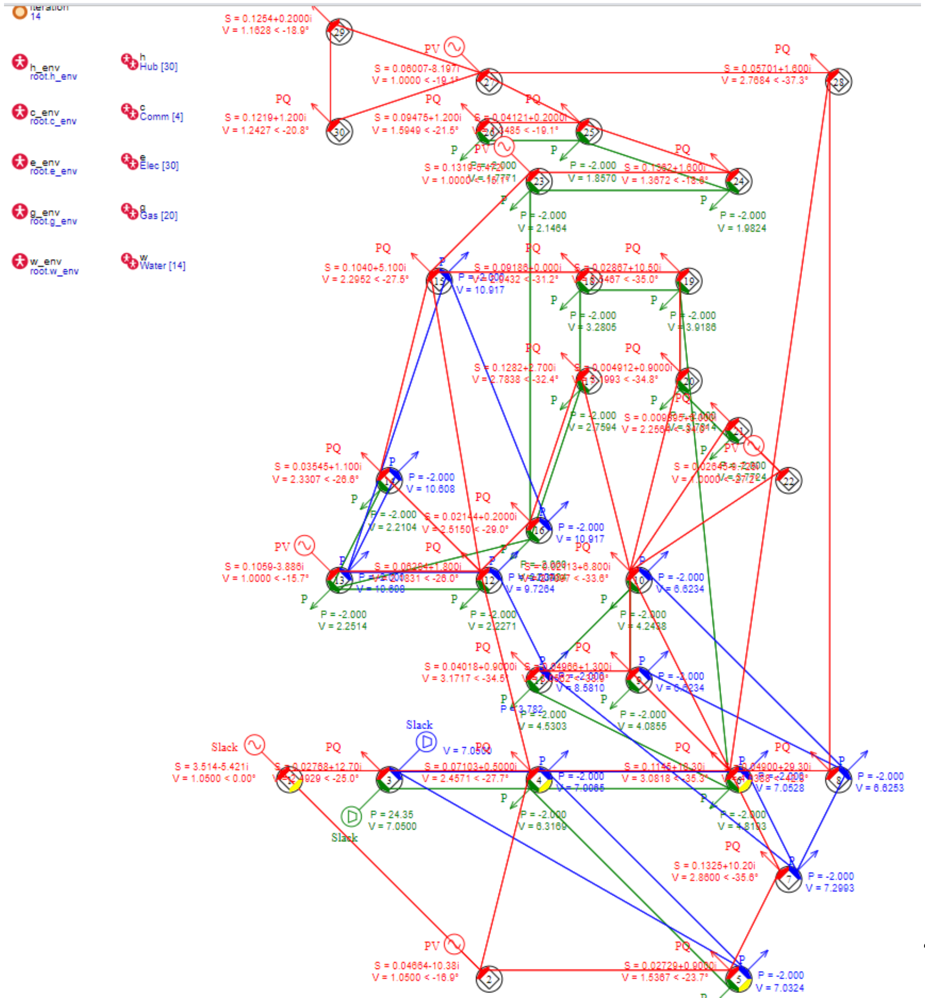
District heating 14 node network [6]

Model demonstration

Energy flow	Energy carrier	Energy Conductor	Colour
electric	electricity	wires	red
natural gas	gas	pipes	green
thermal	water	pipes	blue



Simulation results at node 5



Future model development

From static to dynamic

- Current model simulates multi-energy flow with static input
- Future model will integrate dynamic energy consumption profile (e.g. 24 hrs energy consumption profile)

Decentralized energy flow optimization

- Agent-based model has promising potential in decentralized optimization of energy flow optimization
- Future model will explore the decentralized optimization of multi-region IES

Reference

[1] Z. Vrontisi, K. Fragkiadakis, M. Kannavou, and P. Capros, “Energy system transition and macroeconomic impacts of a European decarbonization action towards a below 2 °C climate stabilization,” Clim. Change, vol. 162, no. 4, pp. 1857–1875, 2020.
[2] J. M. Gonzalez De Durana, O. Barambones, E. Kremers, and L. Varga, “Agent based modeling of energy networks,” *Energy Convers. Manag.*, vol. 82, pp. 308–319, 2014, doi: 10.1016/j.enconman.2014.03.018.
[3] M. Geidl and G. Andersson, “A modeling and optimization approach for multiple energy carrier power flow,” 2005 IEEE Russ. Power Tech, PowerTech, 2005.
[4] IEEE 30-bus system. http://www.ee.washington.edu/research/pstca/pf30/pg_tca30bus.htm
[5] De Wolf D, Smeers Y. The gas, transmission problem solved by an extension of the simplex algorithm. Manage Sci;46:1454–65,2000.
[6] A. Shabanpour-Haghighi and A. R. Seifi, “Simultaneous integrated optimal energy flow of electricity, gas, and heat,” *Energy Convers. Manag.*, vol. 101, pp. 579–591, Sep. 2015.

Questions?

Thank you!

Questions?

Nicolas Fatras: Does your model also include conversion from one energy subtype to another?

Sharif Khaleghparast: Great presentation. Do you plan to have a more realistic visualization on the GIS or something like that?

Can you say a little bit more about how you define your agents? Is an agent a bus/node or what does your agents "express"?

Towards what goals would you aim to implement optimization? How would you allow the optimization towards multiple goals? (e.g. grid expansion costs, maximum local autarky, co2 displacement)