Advanced Optimization and AI for Sustainable Multi-Energy Microgrids with Green Hydrogen Integration

MESPO (Multi-Energy System Planning & Operation) Team

Dr. Zhengmao Li

Assistant Professor

Aalto-yliopisto
Aalto-universitetet
Aalto University

https://www.linkedin.com/in/zhengmao-li/



MESPO (Multi-Energy System Planning & Operation) Research Team

https://mespoteam.github.io/

Aalto University
School of Electrical
Engineering

Supervisor



Education Background

2016-2020 **Nanyang Technological University** Ph.D.
School of Electrical and Electronic Engineering
2020-2023 **Stevens Institute of Technology & ETH Zurich** Postdoc
Department of Electrical & Computer Engineering
2023-Now, Dr. Li joined **Aalto University** as an Assistant Professor.

Research Interest

Optimal Planning and Operation of Multi-energy systems (MES):

1. Planning and operation of MES, i.e., **microgrids, ships, airports, buildings,** etc., with power, heat/cooling, water, and hydrogen.
2. Dealing with uncertainties from **renewables,** temperature, prices, etc., via mathematical methods.
3. Online **data-driven (AI)** operation with reinforcement learning or deep learning.
4. **Market mechanism** design with electric vehicles and **P2P trading**.
5. **Resilience** enhancement of the MES with **climate change**.

A/P. Li Zhengmao

Official Website: *https://people.aalto.fi/zhengmao.li*
Google Scholar: *https://scholar.google.com/citations? user =B5_2lu0AAAAJ&hl=en*

Aalto-yliopisto
Aalto-universitetet
Aalto University

MESPO (Multi-Energy System Planning & Operation) Research Team

https://mespoteam.github.io/

Aalto University
School of Electrical Engineering

Team Introduction



Supervisor



Li Zhengmao, Assistant Professor (05 2023)

*Citation: **5414**; **18** High cited papers (first author 11); 7 Hot papers (0.1%, first author)*
*TOP **2%** researcher, **Best** reviewers*

Students (all with hydrogen)

PhD students:

Fei Zhineng (Green ships and shipboards)
Jia Xueyong (AI + Green energy systems)
Saeid Amanpour (Green seaport with crane)

Co-supervised students and RA(masters):

Li Zhongtian (Green airport)
Long Haixiang (AI+ water system)

Course on Hydrogen System (AI+)

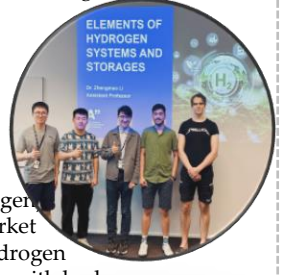


Course Name

Element of Hydrogen Systems and Storages

Responsible Teacher

Dr. Zhengmao. Li



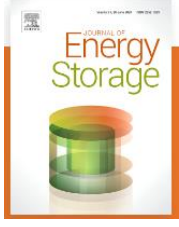
Course General Content

- Units in hydrogen systems
- Electrolyzer (power to hydrogen)
- Hydrogen and electricity market
- Electricity operation with hydrogen
- Low carbon system operation with hydrogen
- Hydrogen System Future

Representative paper

Zhao, A.P., Li, S., Xie, D. **Li Z**, et al. Hydrogen as the nexus of future sustainable transport and energy systems. *Nat Rev Electr Eng* (2025). https://doi.org/10.1038/s44287-025-00178-2

Academic services



11.8 CiteScore | 9.4 Impact Factor

Journal of Energy Storage

Guest Editor



Prof. Dr. Zhengmao Li
Department of Electrical Engineering and Automation, Aalto University, FI-00076 Aalto, Finland
Email: zhengmao.li@aalto.fi
https://people.aalto.fi/zhengmao.li

Journal lists for editor positions

- IEEE Transactions on Sustainable Energy
- IEEE Transactions on Transportation Electrification
- IEEE Transactions on Industry Application
- IEEE Transactions on Consumer Electronics
- IET Renewable Power Generation
- IET Energy Conversion and Economics
- IET Smart Grid

Ongoing work

Aalto University
School of Electrical Engineering

- **Smart Operation of Multi-Energy Systems with Green Hydrogen via Advanced AI+Mathematics Approaches**

Smart, Economic Reliable & Sustainable

System structure

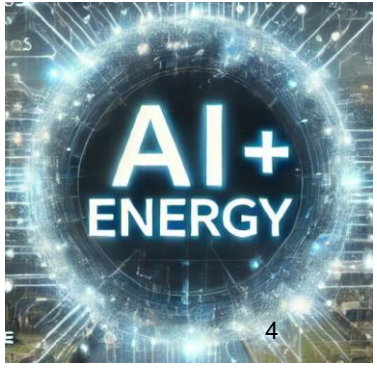
- ☐ Multi-energy microgrids
- ☐ Smart buildings
- ☐ Smart ships and ports
- ☐ Agri-culture system
- ☐ Flights and airports
- ☐ etc.

Energy forms

- ☐ Electricity
- ☐ Heat and cooling
- ☐ Green hydrogen
- ☐ Water
- ☐ Transportation
- ☐ etc.

Methods

- ☐ Model-based
- ☐ Deep learning
- ☐ DRL
- ☐ LLM
- ☐ etc.



Affiliation

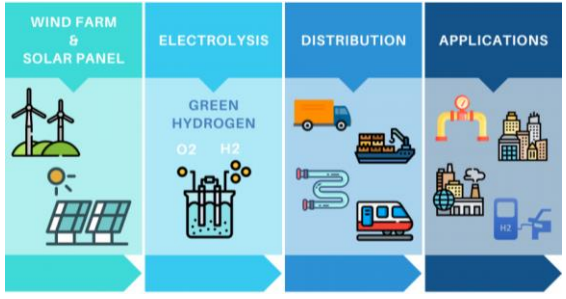
Leader: *AI+Energy sector in Finnish Center of Artificial Intelligence (FCAI)*
Member: *European Laboratory for Learning and Intelligent Systems (ELLIS)*
Finnish Quantum Flagship

Robust Operation of Electricity-Gas-Heat Integrated Multi-Energy Microgrids

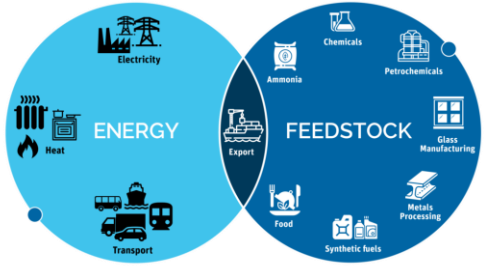
R. Zhang, Y. Chen, Z. Li*, et al, Two-stage Robust Operation of Electricity-Gas-Heat Integrated Multi-Energy Microgrids Considering Heterogeneous Uncertainties, Applied Energy, early access, 2024

Aalto University
School of Electrical Engineering

Background Information



Research Status



Research Contributions



Current Background

- Multi-energy Coordination
- Low carbon goals
- Uncertainties - Reliability

Literature Review

- Current multi-energy research is not comprehensive and flexible
- Power to hydrogen and carbon trading model are not considered
- Uncertainness are not well handled which affects the system reliability

Framework:
Comprehensive multi-energy microgrids

Modelling:
Novel power to hydrogen & heat modelling, carbon trading

Method:
Two-stage robust optimization

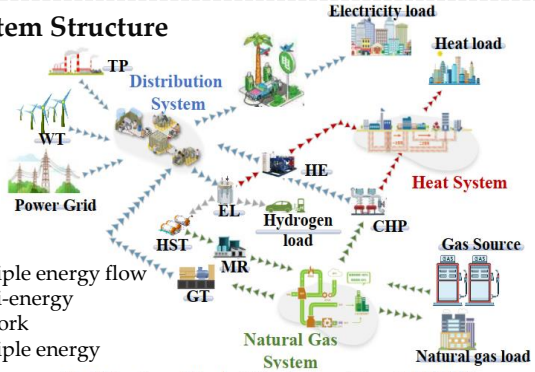
Robust Operation of Electricity-Gas-Heat Integrated Multi-Energy Microgrids

R. Zhang, Y. Chen, Z. Li*, et al, Two-stage Robust Operation of Electricity-Gas-Heat Integrated Multi-Energy Microgrids Considering Heterogeneous Uncertainties, Applied Energy, early access, 2024

Aalto University
School of Electrical Engineering

System Modelling

System Structure



- Multiple energy flow
- Multi-energy network
- Multiple energy loads

Fig. 1 Structure of the electricity-heat-gas integrated MEMG

Power to hydrogen and heat

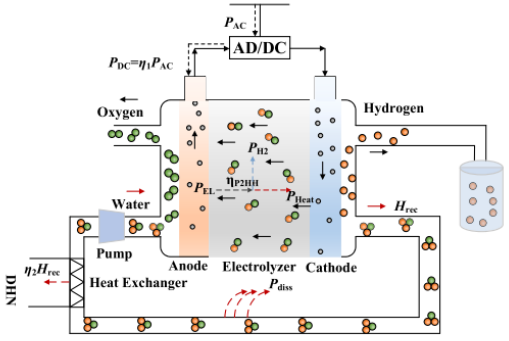


Fig. 2. Configuration of the P2HH system.

Problem Formulation

Objective Function & Constraints

$$\min f_1 = \min \sum_{t=1}^{T} (f_{buy}(t) + f_{sto}(t) + f_{cpl}(t) + f_{DG}(t) + f_{CO_2}^{tax} - f_{CO_2}^{MR})$$

$$\begin{cases} f_{buy}(t) = c_e^t P_{grid,t} + c_{gas} F_{gas,t} \\ f_{sto}(t) = c_{sh} E_t \\ f_{cpl}(t) = c_{elz} P_{elz}^t + c_{CHP}(P_{CHP}^t + Q_{CHP}^t) + c_{MR} P_{MR}^t + c_{GT} P_{GT,t} \\ f_{DG}(t) = c_w P_w^t \end{cases}$$

Two-stage Robust Optimization

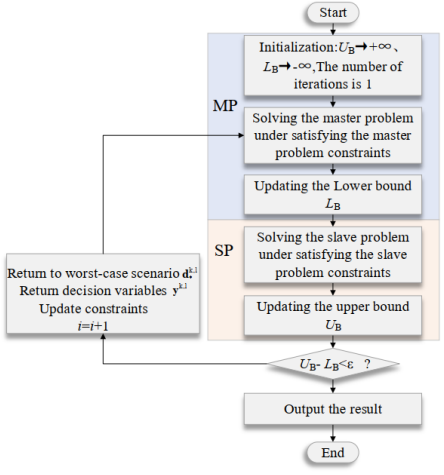


Fig.4 Flowchart of C&CG algorithm

Case Study

Real System Structure

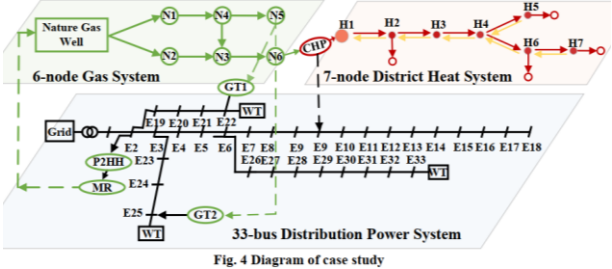


Fig. 4 Diagram of case study

Simulation Results

Table 4 Comparison of dispatching results

Case	Utilized wind power(10^4kW)	Total costs(10^4¥)	Gas Purchase costs (¥)	Carbon sequestration benefits(¥)
1	2.13	2.12	5381.23	0
2	2.20	1.69	87.87	884.60

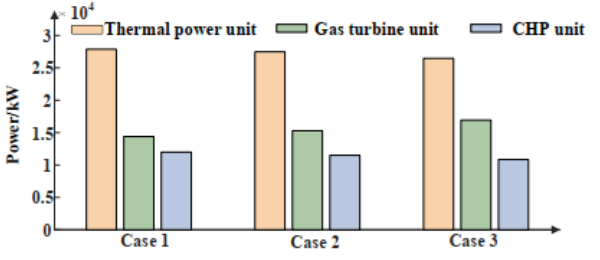


Fig. 8 Dispatch results of three cases

Coordinated Operation of Green Hydrogen Integrated Multi-Energy Ship Microgrids

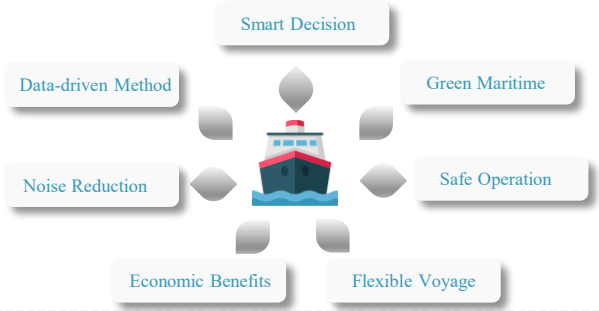
Aalto University
School of Electrical Engineering

Z. Fei, Z. Li*, et al., "Two-Stage Coordinated Operation of A Green Multi-Energy Ship Microgrid with Underwater Radiated Noise by Distributed Stochastic Approach," *IEEE Trans. Smart Grid*, early access, Oct. 17, 2024, doi: 10.1109/TSG.2024.3482980.

Background Information



Research Status



Research Contributions



Current Background

- Multi-energy ship building grid
- Green shipping transformation
- Flexibility enhancement

Literature Review

- Current multi-energy operation in ship research is not comprehensive
- Green hydrogen application and freshwater are not considered
- Flexibility in ship operation can be further enhanced

Framework:
Green hydrogen integrated multi-energy ship microgrids operation considering uncertainties

Modelling:
Multi-energy complementation, underwater radiated noise, flexible voyage, ship swinging, uncertainty correlation

Algorithm:
Tow-stage Distributed Stochastic Approach, Vine-Copula method

Coordinated Operation of Green Hydrogen Integrated Multi-Energy Ship Microgrids

Aalto University
School of Electrical Engineering

Z. Fei, Z. Li*, et al., "Two-Stage Coordinated Operation of A Green Multi-Energy Ship Microgrid with Underwater Radiated Noise by Distributed Stochastic Approach," *IEEE Trans. Smart Grid*, early access, Oct. 17, 2024, doi: 10.1109/TSG.2024.3482980.

System Modelling

❑ System Structure

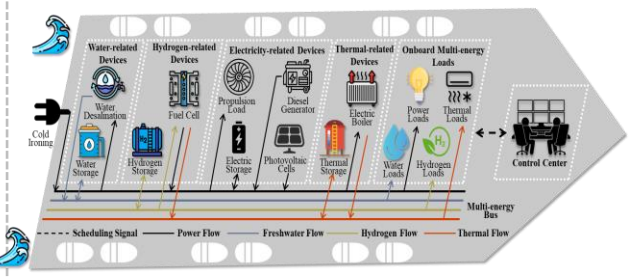


Fig. 1. Node voltage (DRL)

❑ Underwater Radiated Noise

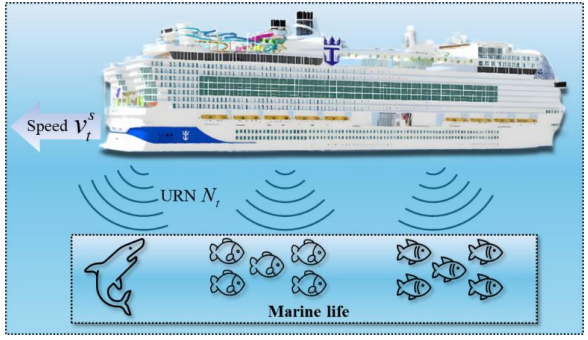


Fig. 2. The impact of URN on marine animals.

System Modelling

❑ Flexible Voyage

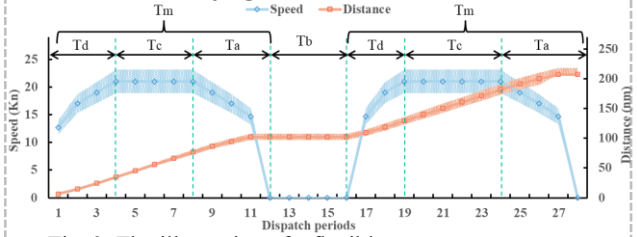


Fig. 3. The illustration of a flexible voyage.

$$\begin{cases} \left(1-\alpha_{speed}\right)v_n^s \le v_t^s \le \left(1+\alpha_{speed}\right)v_n^s. \\ Dist_t^s = Dist_{t-1}^s + v_t^s \Delta t. \\ \begin{cases} \left(1-\alpha_{mid}\right)Dist_{t,n}^s \le Dist_t^s \le \left(1+\alpha_{mid}\right)Dist_{t,n}^s, t \ne N_t \\ Dist_{t,n}^s \le Dist_t^s \le \left(1+\alpha_{final}\right)Dist_{t,n}^s, t = N_t \end{cases} \end{cases}.$$

Correlated Uncertainty Description with Vine-Copula

$$\begin{cases} f_{\{\square\}}\left(\xi_t^P, \xi_t^T, \xi_t^H, \xi_t^W, \xi_t^{PV}\right) = \prod_{m=1}^{4}\prod_{n=1}^{5-m} c_{m,m+n|w_{n,m}}\left(F_{m|w_{n,m}}, F_{m+n|w_{n,m}}\right) \\ \qquad \times\left[\prod_{\{\square\}} f\left(\xi_t^{\{\square\}}\right)\right], \{\square\} \in [P,T,H,W,PV] \\ F_{m|n} = F\left(U_m|U_n\right) = \partial C_{u_m,u_n}(U_m,U_n,\alpha_{mn})/\partial U_n \end{cases}$$

System Modelling

❑ PV System with Ship Swinging

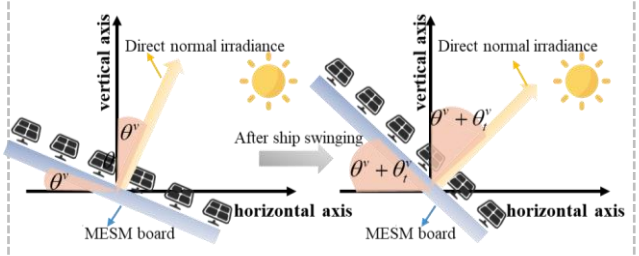


Fig. 4. The impact of ship swinging on PV's output.

$$\begin{cases} P_{i,t}^{PV} = \eta_t^{PV} \times A^{PV} \times I_t^{PV}. \\ \eta_t^{PV} = \eta_{ref}^{PV} \times \alpha^{PF} \times \alpha^{Tr} \times \eta^{PT} \times \left[1-\alpha^T \times \left(T_t - T_{ref}\right)\right]. \\ \begin{cases} \cos\chi^v = \sin\theta^{SDA}\sin\theta^L + \cos\theta^{SDA}\cos\theta^L\cos\theta^{SA} \\ \theta^{SDA} = 23.44 \times \sin\left[360 \times \left((d-80)/365.25\right)\right] \\ \theta^{SA} = \left(LST-12\right) \times 360/24 \end{cases} \end{cases}$$

Coordinated Operation of Green Hydrogen Integrated Multi-Energy Ship Microgrids

Aalto University
School of Electrical Engineering

Z. Fei, Z. Li*, et al., "Two-Stage Coordinated Operation of A Green Multi-Energy Ship Microgrid with Underwater Radiated Noise by Distributed Stochastic Approach," *IEEE Trans. Smart Grid*, early access, Oct. 17, 2024, doi: 10.1109/TSG.2024.3482980.

Problem Formulation

❑ Objective Function

Minimize the total operational costs

$$\min \sum_{t\in N_T}\left(C_t^{FU}+C_t^{ST}+C_t^{OM}+C_t^{EM}+C_t^{CI}+C_t^{CL}\right)\Delta t.$$

$$\begin{cases} C_t^{FU}=\sum_{g\in N_G}\left[a_g^{DG}(P_{g,t}^{DG})^2+b_g^{DG}P_{g,t}^{DG}+c_g^{DG}U_{g,t}^{DG}\right]+\lambda_t^{H}H_t^{Buy} \\ C_t^{ST}=\sum_{g\in N_G}\max\left\{0,U_{g,t}^{DG}-U_{g,t-1}^{DG}\right\}\lambda_g^{ST} \\ C_t^{OM}=\left[\begin{array}{l}\sum_{g\in N_G}\lambda_{M,g}^{DG}P_{g,t}^{DG}+\sum_{\{\square\}=P,T,H,W}\lambda_M^{\{\square\}}\left(\{\square\}_t^{D}+\{\square\}_t^{C}\right)\\ +\sum_{f\in N_F}\lambda_{M,f}^{FC}P_{f,t}^{FC}+\sum_{\omega\in[PtC,WD]}\lambda_M^{\omega}P_t^{\omega}\end{array}\right] \\ C_t^{EM}=\lambda^{CP}\times\sum_{g\in N_G}\left[a_{E,g}^{DG}(P_{g,t}^{DG})^2+b_{E,g}^{DG}P_{g,t}^{DG}+c_{E,g}^{DG}U_{g,t}^{DG}\right] \\ C_t^{CI}=\lambda_t^{CI}P_t^{CI} \\ C_t^{CL}=\lambda^{EC}\{\square\}_t^{EC}+\lambda^{LS}\{\square\}_t^{LS},\{\square\}=P,T,H,W \end{cases}.$$

❑ Constraints

$$\begin{cases} \sum_{f\in N_F}T_{f,t}^{FC}+T_t^{PtC}+T_t^{D}-T_t^{EC}=T_t^{Sl}-T_t^{LS}+T_t^{C} \\ H_t^{Buy}+H_t^{D}-H_t^{EC}=H_t^{Sl}-H_t^{LS}+\sum_{f\in N_F}H_{f,t}^{FC}+H_t^{C} \\ W_t^{WD}+W_t^{D}-W_t^{EC}=W_t^{Sl}-W_t^{LS}+W_t^{C} \end{cases}.$$

$$[0,0]\le\left[\{\square\}_t^{EC},\{\square\}_t^{LS}\right]\le\left[\{\square\}_{t,\max}^{EC},\{\square\}_{t,\max}^{LS}\right],\{\square\}=P,T,H,W.$$

Two-stage Distributed Coordination Operation

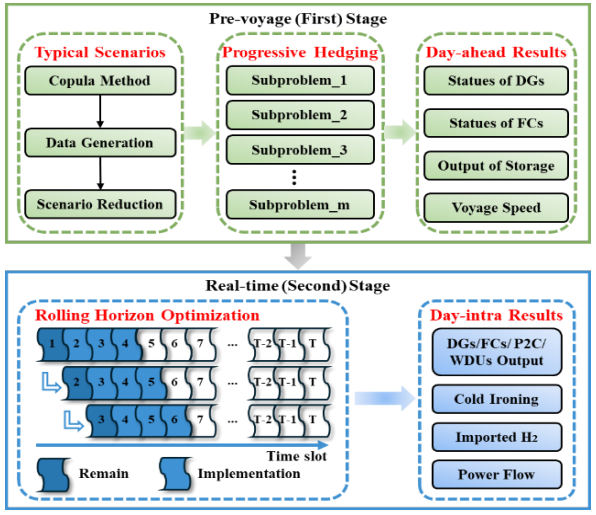


Fig. 5.The two-stage distributed coordinated structure.

Minimize the sum of first- and expected second-stage costs

$$\min_{\text{First Stage}}\ \mathbf{c}_1^T\mathbf{x}+\underbrace{\sum_{s\in N_s}p_s\cdot\mathbf{c}_2^T\mathbf{y}_s}_{\text{Second Stage}}\quad(\text{Pre-voyage stage})$$

$$s.t.,\mathbf{x}\in\boldsymbol{\chi}$$

$$\mathbf{y}_s\in\left\{y\middle|\mathbf{Ax}+\mathbf{By}_s\ge\mathbf{h}_1,\mathbf{Ex}+\mathbf{Fy}_s=\mathbf{h}_2\left(\boldsymbol{\xi}_s\right)\right\}.$$

Case Study

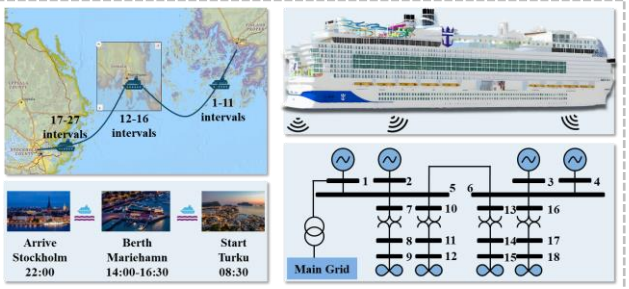


Fig. 6. The voyage and the power distribution network

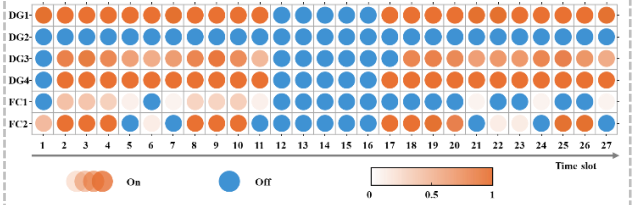


Fig. 7. Unit commitment of DGs and FCs.

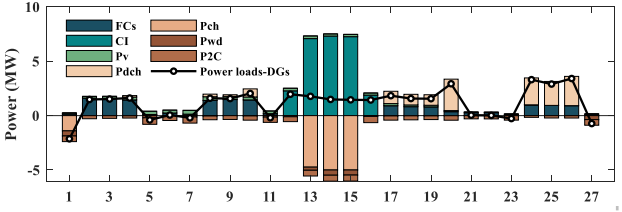


Fig. 8. The power balance for MESM.

Online Operation of Multi-energy Microgrids via Safe Deep Reinforcement Learning

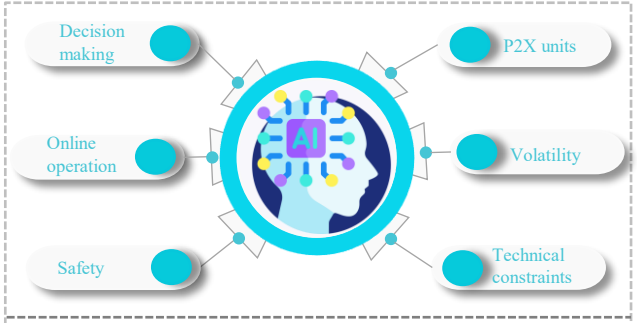
X. Jia, Z. Li*, et al, Coordinated Operation of Multi-energy Microgrids Considering Green Hydrogen and Congestion Management via Safe Reinforcement Learning. Applied Energy

Aalto University
School of Electrical Engineering

Background Information



Research Status



Research Contributions



Current Background

- Multi-energy Microgrids
- Green hydrogen+P2X
- Artificial intelligence application

Literature Review

- Current multi-energy microgrid research is not comprehensive
- Green hydrogen application and P2X are not considered
- Safety is not well handled in current AI algorithms which affects system security

Framework:
Comprehensive multi-energy microgrids

Modelling:
Power-to-hydrogen-heat, multi-energy network, Electrothermal Coupling Power Flow, thermal flow

Method:
A safety-constrained deep reinforcement learning approach (AI)

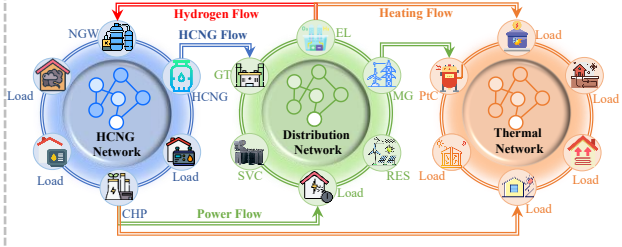
Online Operation of Multi-energy Microgrids via Safe Deep Reinforcement Learning

X. Jia, Z. Li*, et al, Coordinated Operation of Multi-energy Microgrids Considering Green Hydrogen and Congestion Management via Safe Reinforcement Learning. Applied Energy

Aalto University
School of Electrical Engineering

System Modelling

System Structure



$$\begin{cases} V_t^{cell} = V_t^{rev} + V_t^{act} + V_t^{ohm} + V_t^{con} \\ V_t^{rev} = a - b \cdot T_t^{cell} + c \cdot T_t^{cell} ln(T_t^{cell}) + d \cdot (T_t^{cell})^2 \\ V_t^{act} = (\mathrm{R}\, T_t^e / 2\alpha^{a/c} \mathrm{F}) \cdot \arcsin h(I_t^{cell} / (i_0^{a/c} \cdot A^{cell})) \\ V_t^{ohm} = (\delta' \cdot I_t^{cell}) / (A^{cell} \cdot \sigma') \end{cases}$$

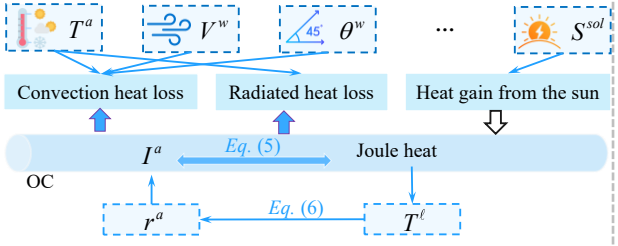
- The dynamic thermal model

$$\begin{cases} C^e \cdot dT^{cell} / dt = H_t^{cell} - H_t^{loss} - H_t^{cool} \\ H_t^{cell} = (V_t^{cell} - V^{th}) \cdot I_t^{cell} \\ H_t^{loss} = (T_t^{cell} - T_t^e) \times h \end{cases}$$

$$T_{t+1}^{cell} = T_t^{cell} + (H_t^{cell} - H_t^{loss} - H_t^{cool}) \cdot \Delta t / C^e, \forall t$$

System Modelling

Electrothermal Coupling Power Flow

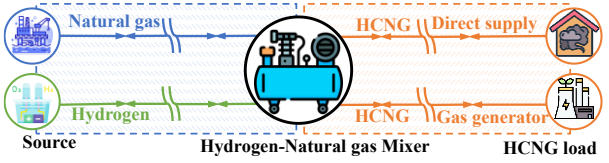


The steady-state balance of the overhead line

$$\begin{cases} P_{l,t}^\ell = V_{i,t}^b V_{j,t}^b (G_{ij,t}^\ell (T_{l,t}^\ell) \cos\theta_{ij,t}^\ell + B_{ij,t}^\ell (T_{l,t}^\ell) \sin\theta_{ij,t}^\ell) \\ \qquad + (V_{i,t}^b)^2 G_{ij,t}^\ell (T_{l,t}^\ell) \\ Q_{l,t}^\ell = V_{i,t}^b V_{j,t}^b (G_{ij,t}^\ell (T_{l,t}^\ell) \sin\theta_{ij,t}^\ell - B_{ij,t}^\ell (T_{l,t}^\ell) \cos\theta_{ij,t}^\ell) \\ \qquad - (V_{i,t}^b)^2 B_{ij,t}^\ell (T_{l,t}^\ell) \\ (I_{l,t}^\ell)^2 = F_t^2 (V_{i,t}^b, V_{j,t}^b, \theta_{i,t}^b, \theta_{j,t}^b, r_{l,t}^\ell (T_{l,t}^\ell)) \\ \qquad = ((V_{i,t}^b)^2 + (V_{j,t}^b)^2 - 2V_{i,t}^b V_{j,t}^b \cos\theta_{ij,t}^\ell) / ((r_{l,t}^\ell (T_{l,t}^\ell))^2 + X_l^2) \end{cases}$$

System Modelling

Hydrogen-compressed Natural Gas Flow



The one-dimensional steady-state compressible gas flow

$$\frac{dp}{dx} + \frac{\lambda}{2D^p} \frac{\mathrm{Z R}\, T^g}{pMA^p} f|f| + \frac{f^2 \mathrm{R}}{M \cdot (A^p)^2} \frac{d}{dx}\left(\frac{\mathrm{R}\, T^g}{p}\right) = 0$$

The steady-state pressure drop across a duct is expressed as follows:

$$p_j - p_i = \frac{\upsilon_2}{\upsilon_1} \ln\left(\frac{\upsilon_1 p_j + \upsilon_2}{\upsilon_1 p_i + \upsilon_2}\right) - \upsilon_1 \frac{\lambda \mathrm{R}\, T^g L^p}{2D^p M (A^p)^2} f_l |f_l|$$

Thermal Flow

$$H_{i,t}^p = C^p m_{l,t}^s (T_{i,t}^s - T_0^h)$$

$$\begin{cases} T_{j,t}^{s/r} = (T_{i,t}^{s/r} - T_t^e) e^{-(\lambda/L_l^p)/(C^p \cdot m_{l,t}^{s/r})} + T_t^e \\ \sum_{i \in \mathbf{P}_n^{s/r,(-)}} (m_{i,t}^{s/r} \cdot T_{i,t}^{s/r,(-)}) = \sum_{i \in \mathbf{P}_n^{s/r,(+)}} (m_{i,t}^{s/r}) \cdot T_{i,t}^{s/r,(+)} \end{cases}$$

Online Operation of Multi-energy Microgrids via Safe Deep Reinforcement Learning

Aalto University
School of Electrical Engineering

X. Jia, Z. Li*, et al, Coordinated Operation of Multi-energy Microgrids Considering Green Hydrogen and Congestion Management via Safe Reinforcement Learning. Applied Energy, 2025

Problem Formulation

Constrained Markov Decision Process

i) **State**: The state space is defined as:

$$s_t = \begin{Bmatrix} t, \kappa_t^e, \boldsymbol{P}_t^{load}, \boldsymbol{Q}_t^{load}, \boldsymbol{H}_t^{load}, \boldsymbol{f}_t^{load}, P_t^{wt}, P_t^{pv} \\ \chi_t, P_{t-1}^{chp}, P_{i,t-1}^{gt}, Q_{i,t-1}^{svc}, \Delta \boldsymbol{V}_{t-1}^{b}, \Delta \boldsymbol{P}_{t-1}^{line} \end{Bmatrix}$$

ii) **Action**: The action set is defined as:

$$a_t = \{a_t^{chp}, a_{i,t}^{gt}, a_{i,t}^{svc}\}$$

iii) **Reward**: To evaluate the performance of the agent, the reward is defined as follows:

$$r_t(s_t, a_t) = -(C_t^{om} + C_t^{e} + C_t^{ng})$$

iv) **Constraints**: Two safety constraints, i.e., **voltage limits** and **line capacity limits**, are also considered to ensure system reliability and safety. :

$$c_{1,t}(s_t, a_t) = \max([V_{min} - \boldsymbol{V}_t^b]^+ + [\boldsymbol{V}_t^b - V_{max}]^+)$$

v) **Objective Function**: To find an optimal policy:

$$\max_{\pi_\phi} \mathop{\mathrm{E}}_{(s_t, a_t) \sim \rho_\pi} \left[\sum_t \gamma \cdot r_t(s_t, a_t) \right]$$

$$s.t.\ \ c_{i,t}(s_t, a_t) \le d_i, \quad i \in \{1, 2\}$$

vi) **Environment**: The MEMG environment consists of three solvers.

Safe Reinforcement Learning

The Proposed Data-Driven Method Framework

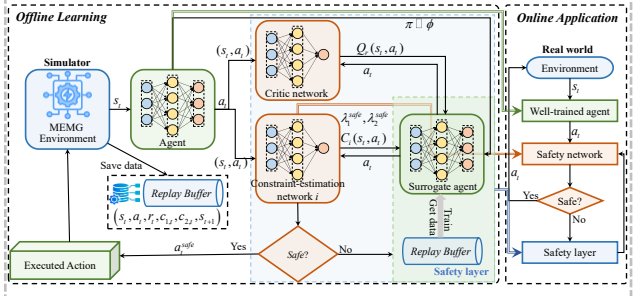


Fig.4 Framework of the Safe-DRL-based solution method.

- This method is divided into two stages:
- **offline learning** and **online application**.

The light blue and light green shaded areas together constitute the **safety layer**, with the light blue area also serving independently to guide policy learning.

Case Study

Test Results

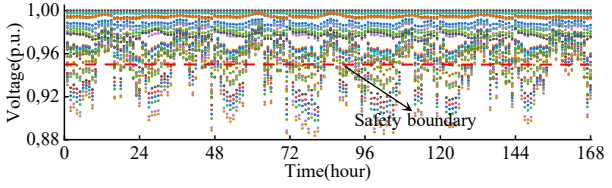


Fig. 5. Node voltage (DRL)

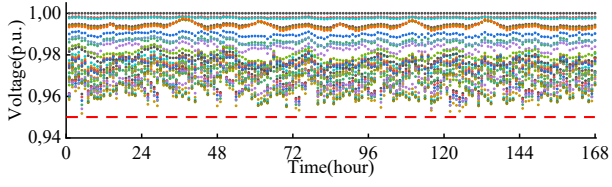


Fig. 6. Node voltage (Safe-DRL)

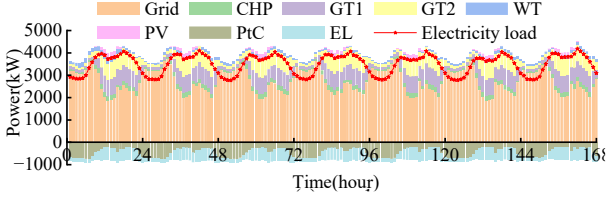


Fig. 8. Power balance condition for MEMG

Multi-energy System Resilience Enhancement Under Extreme Events

Li Z, Xu Y, Wang P, et al. Restoration of a multi-energy distribution system with joint district network reconfiguration via distributed stochastic programming[J]. IEEE Transactions on Smart Grid, 2023, 15(3): 2667-2680.

Aalto University
School of Electrical Engineering

Background and Motivation

- ✓ Extreme events, i.e., earthquake, floods and storms cause **failures and huge damage** in power and thermal networks.
- ✓ **Multi-Energy** Distribution Systems (MDS) face complex challenges from restoration **method** and computation **efficiency**.
- ✓ Traditional methods focus mainly on power networks-**thermal networks are overlooked**.
- ✓ Goal: Enhance **resilience** using comprehensive **restoration** and **solution** method.



2025: Spain Power outage



2025: Earthquake destroyed Myanmar



2025: Los Angeles wildfire

Disasters are more frequent with huge impact!

Aalto-yliopisto
Aalto-universitetet
Aalto University

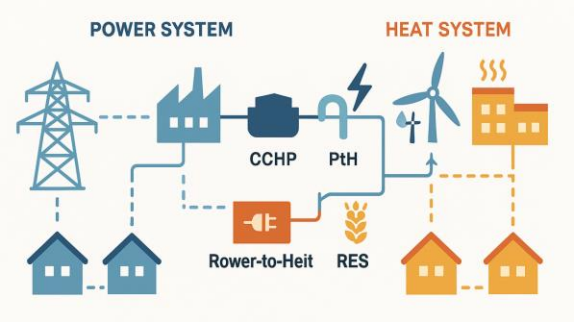
Resilience measures how well, i.e., cost, loss, an energy system can withstand and recover from major disruptions like natural disasters, accidents, or attacks.

Multi-energy System Resilience Enhancement Under Extreme Events

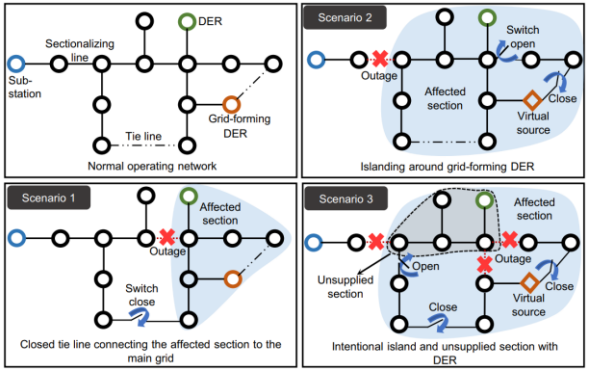
Aalto University
School of Electrical Engineering

Li Z, Xu Y, Wang P, et al. Restoration of a multi-energy distribution system with joint district network reconfiguration via distributed stochastic programming[J]. IEEE Transactions on Smart Grid, 2023, 15(3): 2667-2680.

1: Mutual support from energy sectors



2: Network reconfiguration



Test System:
IEEE 33-bus EN + 43-node TN
15 scenarios modeled, 10 disrupted lines/pipes

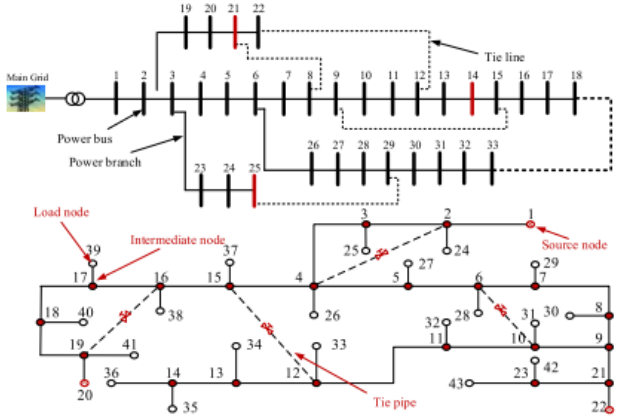


Fig. 7. The schematic diagram of the MDS test system.

SCENARIOS FOR BROKEN LINES AND PIPES [7], [29], [32], [33]

Line	substation,(1,2), (6,26),(32,33)	substation,(2,3), (9,10),(30,31)	substation,(3,4), (8,9),(29,30)
Scenario(s)	s1,s4,s8,s9,s11,s13	s2,s5,s7,s12	s3,s6,s10,s14,s15
Pipe	(3,4),(7,8), (11,12), (17,18)	(2,3),(8,9), (4,15), (18,19)	(4,5), (7,8), (10,11), (16,17)
Scenario(s)	s3,s5,s9,s11	s1,s2,s6,s8,s10,s12	s4,s7,s13,s14,s15

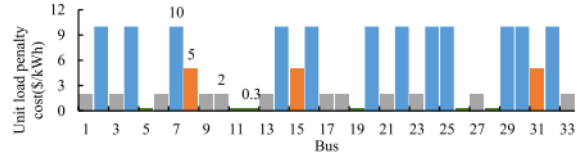


Fig. 8. The unit penalty cost of power loads not supplied on each bus.

Aalto-yliopisto
Aalto-universitetet
Aalto University

Multi-energy System Resilience Enhancement Under Extreme Events

Li Z, Xu Y, Wang P, et al. Restoration of a multi-energy distribution system with joint district network reconfiguration via distributed stochastic programming[J]. IEEE Transactions on Smart Grid, 2023, 15(3): 2667-2680.

Results:

- ✓ Joint reconfiguration significantly reduces unsupplied load effectively
- ✓ Coordinated operation of CCHP, batteries, and thermal storage
- ✓ Fuel allocation and dispatch planning reduce cost and enhance resilience

Restoration cost is 18028.24$

Reserve!

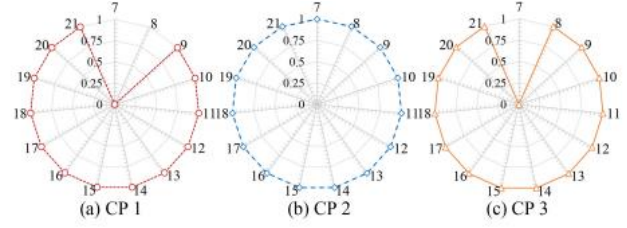


Fig. 16. The Unit commitment of CCHP plants in 3 CPs.

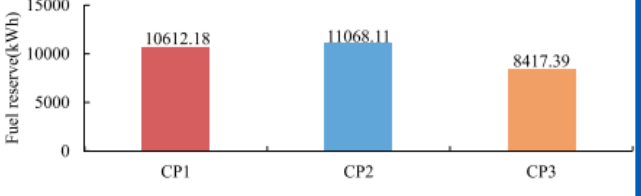


Fig. 15. The pre-fuel allocation for three CPs in the MDS.

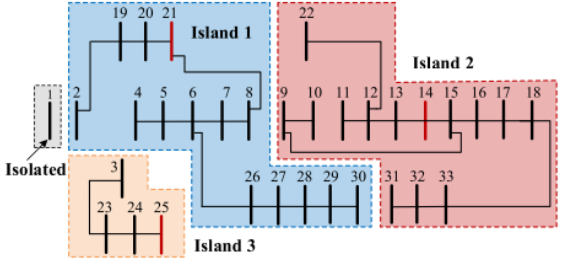


Fig. 17. The reconfiguration of the EN after disasters with 3 islands.

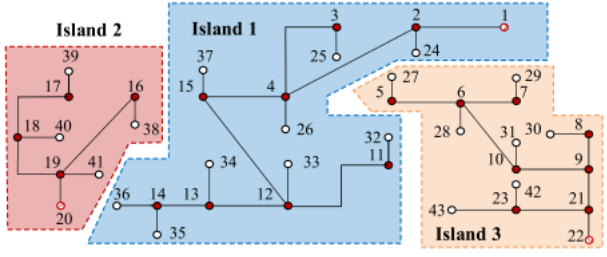


Fig. 18. The reconfiguration of the TN after disasters with 3 islands.

Joint Reconfiguration!

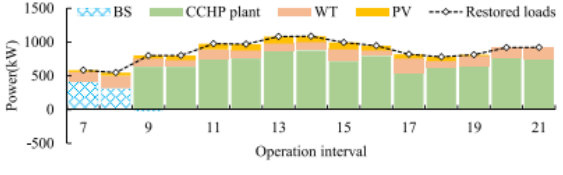


Fig. 19. Power energy balance condition for island 1 of scenario 7.

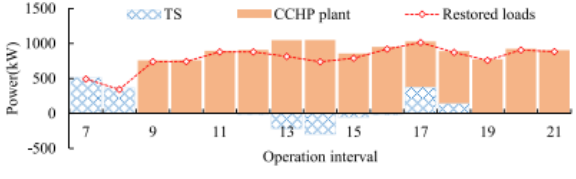


Fig. 20. Thermal energy balance condition for island 1 of scenario 7.

Coordinated Operation!

AI + Energy SIG on FCAI

https://fcai.fi/energy

FCAI Finnish Center for Artificial Intelligence

Aalto University School of Electrical Engineering

Key Notes:

1. Focus & Vision
- AI transformation of energy systems.

2. Goals
- Foster AI and energy collaborations.
- Regular **seminars, workshops**.

3. Research Areas
- AI for Smart Grids
- AI for Green Hydrogen
- AI for Smart Buildings
- AI for Transportation & Mobility
- AI for HVAC Systems
- AI for Water Management
- AI for Battery Systems

4. Impact & Collaboration
- Promoting **intelligent**energy solutions.
- Engaging an **innovation ecosystem**.





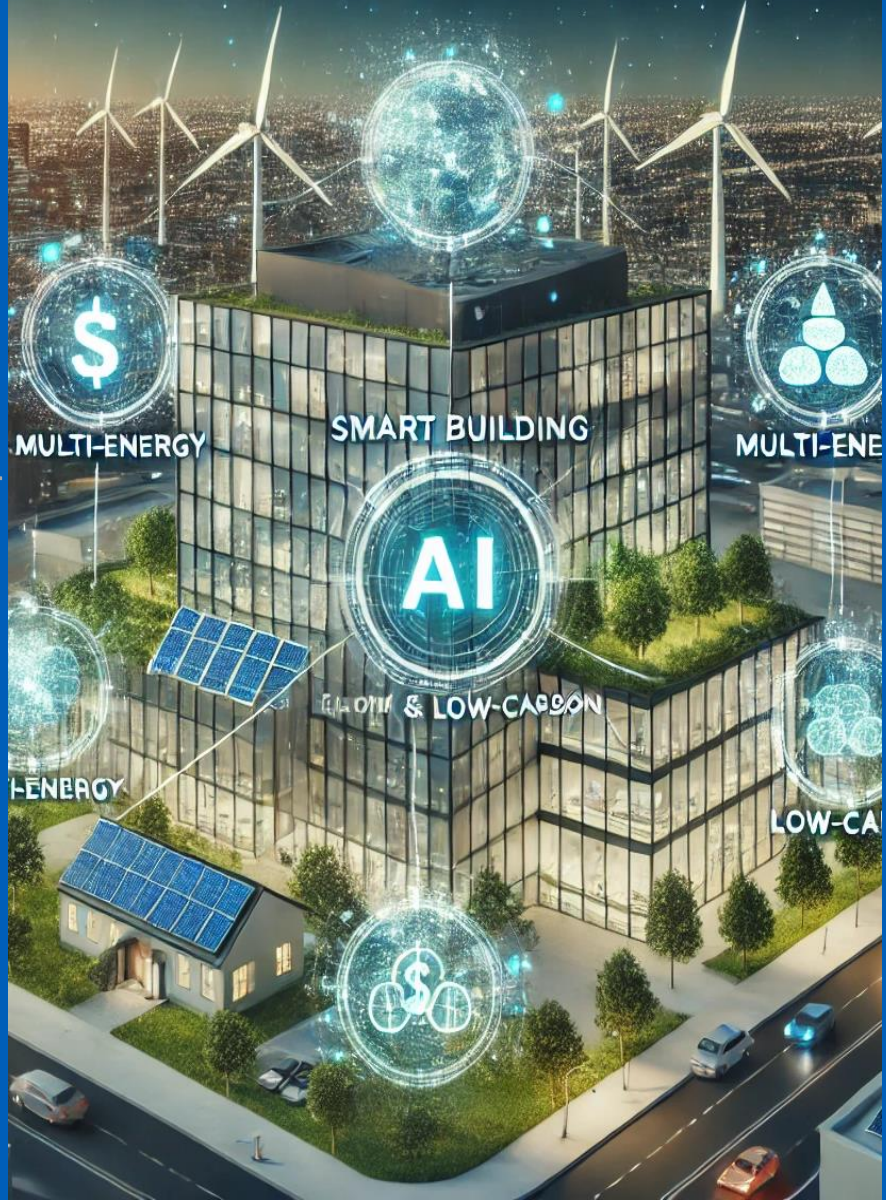




AI+Energy

Linkedin: https://www.linkedin.com/in/zhengmao-li/

Advanced Optimization and AI for Sustainable Multi-Energy Microgrids with Green Hydrogen Integration



Aalto-yliopisto
Aalto-universitetet
Aalto University

Dr. Zhengmao Li

Assistant Professor