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Economic Value of Power-to-Hydrogen Conversion System in Flexibility of Medium-Voltage Distribution Network (MV-DN)

"Super Power to Gas Project"

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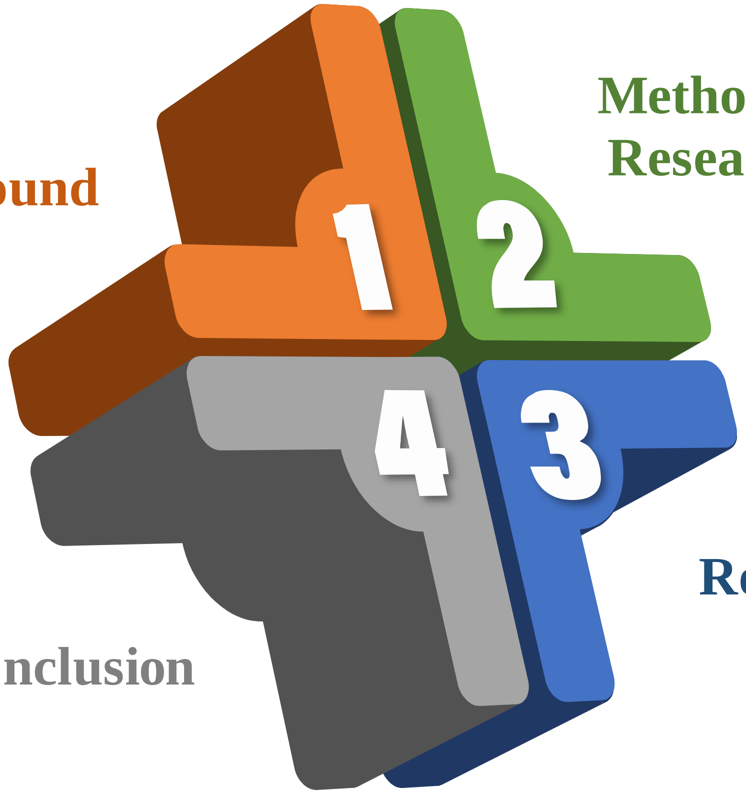
Overview…

Background

Method of Research



Results

Conclusion

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Background

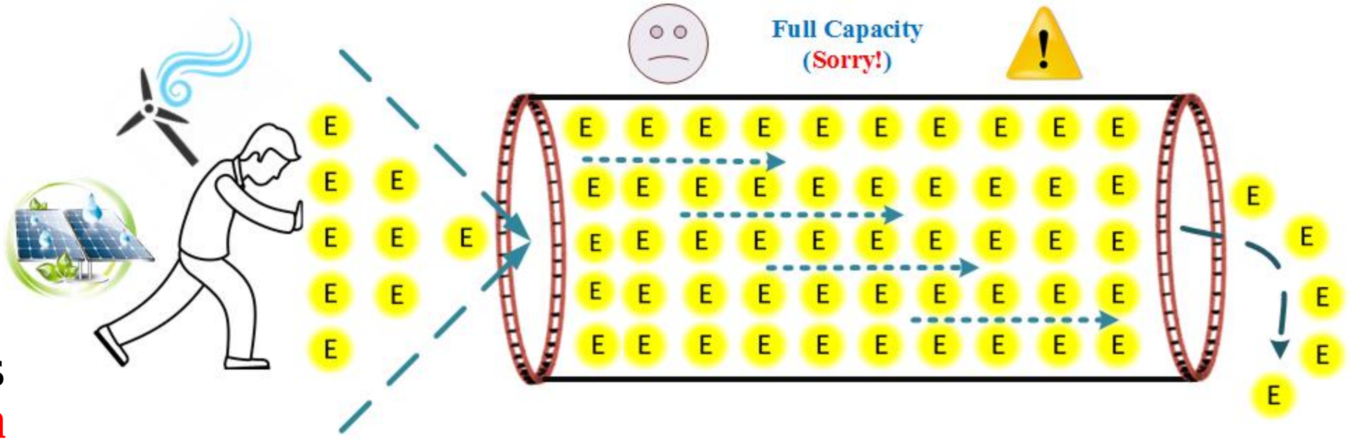
The ongoing expansion of renewable energy sources (RES) in the electricity sector increases the decentralized generation portfolio. In response to this huge integration level of RES, MV-DNs must be upgraded.

However, MV-DNs do not expand as fast as renewables capacity, resulting in **generation curtailment**.

Why Generation Curtailment?

Congestion Problem

Congestion problem occurs when the security constraints of the grid are violated



Security Constraints of Grid:

Thermal Limits: Thermal limits are due to the thermal capability of power system equipment such as cables.

Voltage Limits: Both grid and customer equipment are designed to operate at a certain supply voltage

The main question: How can MV-DNs increase the flexibility for solving the congestion problem?

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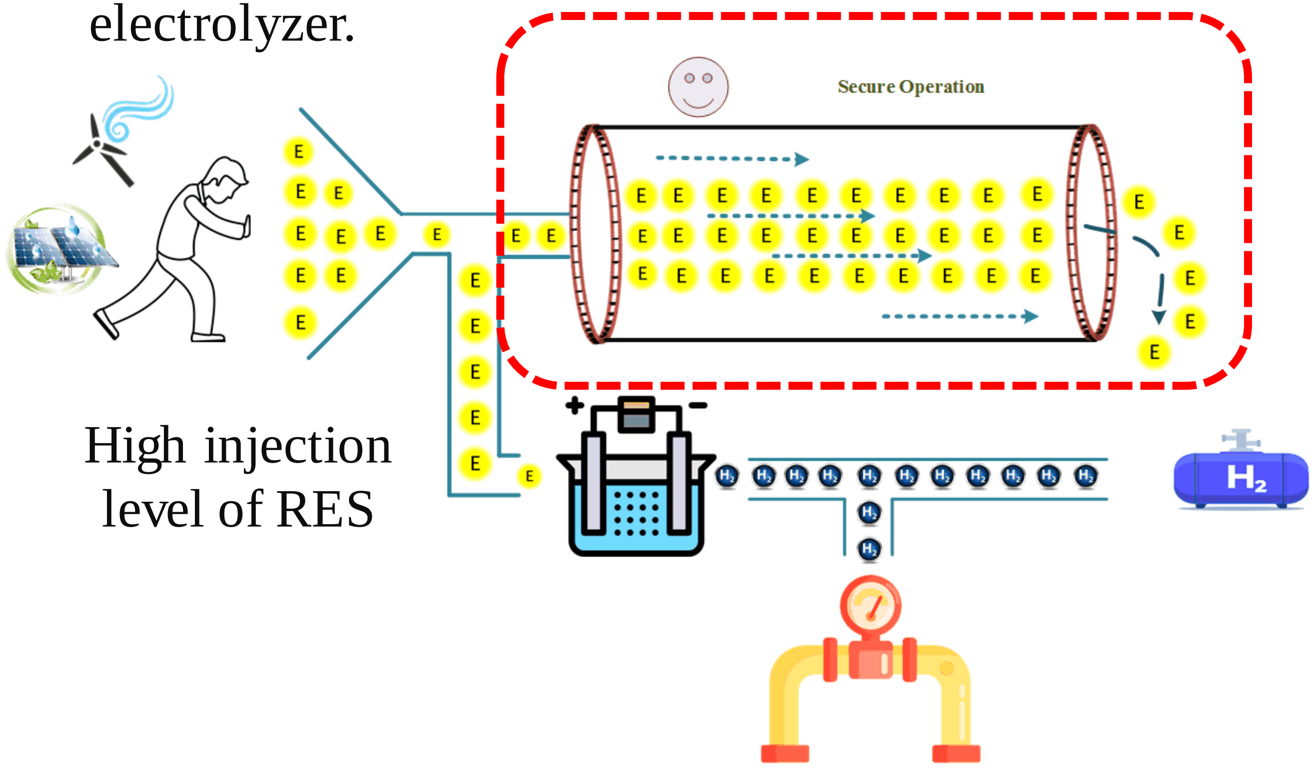
Background…

One of the short-term solutions for improving flexibility can be converting power to hydrogen through electrolyzer.



High injection level of RES

Converting power to hydrogen diminishes amount of the injected RES power into the grid.

Security constraints are not violated.

Network does not suffer from the congestion problem.

Remarkable Point: Distribution system operator (DSO) needs to encourage power to gas conversion systems to be operated in the grid as flexibility providers

Most of times, electricity price is higher than hydrogen price and it is not practical for electrolyzer to be operated in this situation.

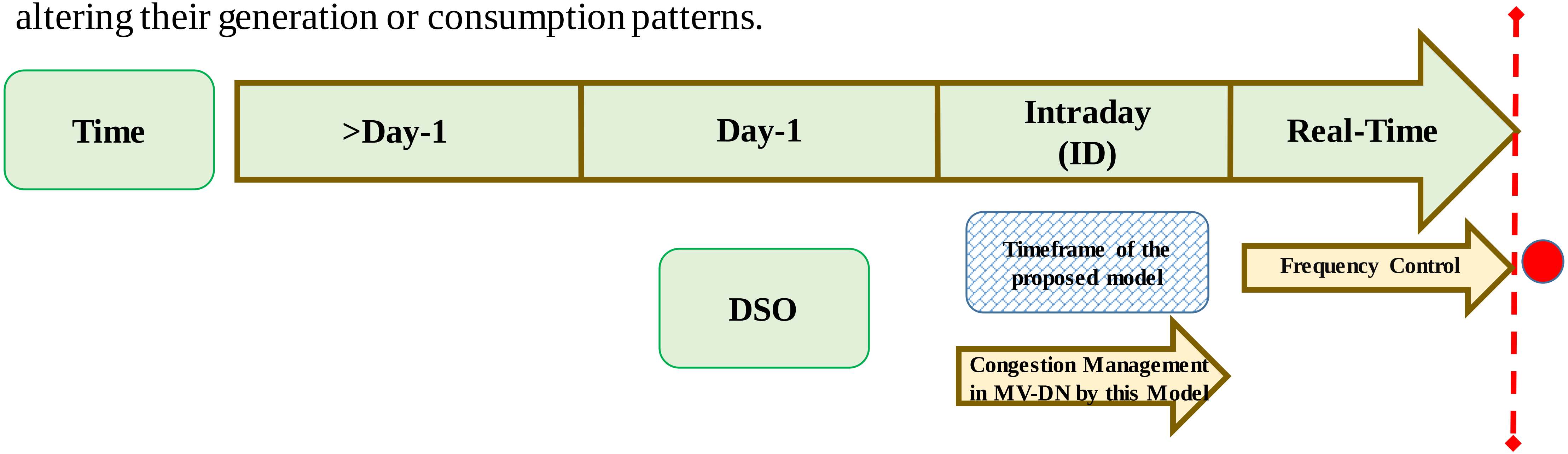
Method of Research

There are two main categories available for dealing with congestion in power systems namely network options and instruments for reshaping of generation and consumption profiles of grid's users.

The proposed model belongs to **the second group**.

This model strives to encourage grid users to amend their consumption and generation behavior in a way that leads to reduce congestion.

The proposed model in this project utilizes **nodal pricing** as an incentive to satisfy market parties for altering their generation or consumption patterns.

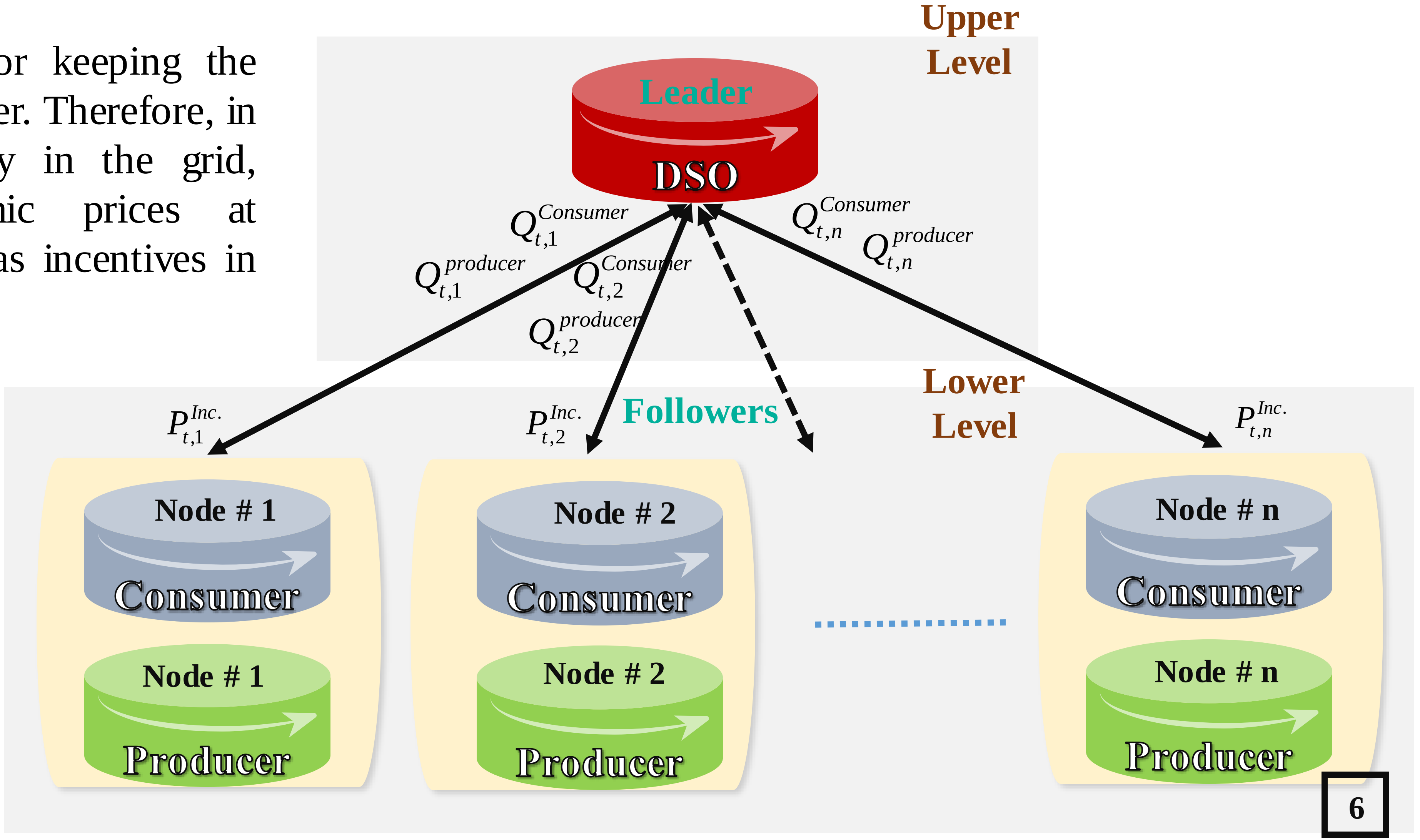


Method of Research…

The DSO is responsible for keeping the network in the optimal manner. Therefore, in order to increase flexibility in the grid, she/he determines dynamic prices at different nodes of the grid as incentives in this model.

Users of the grid modify their generation or consumption levels in response of the received incentives.

In principle, the proposed model is a **single-leader-multiple-followers game**.



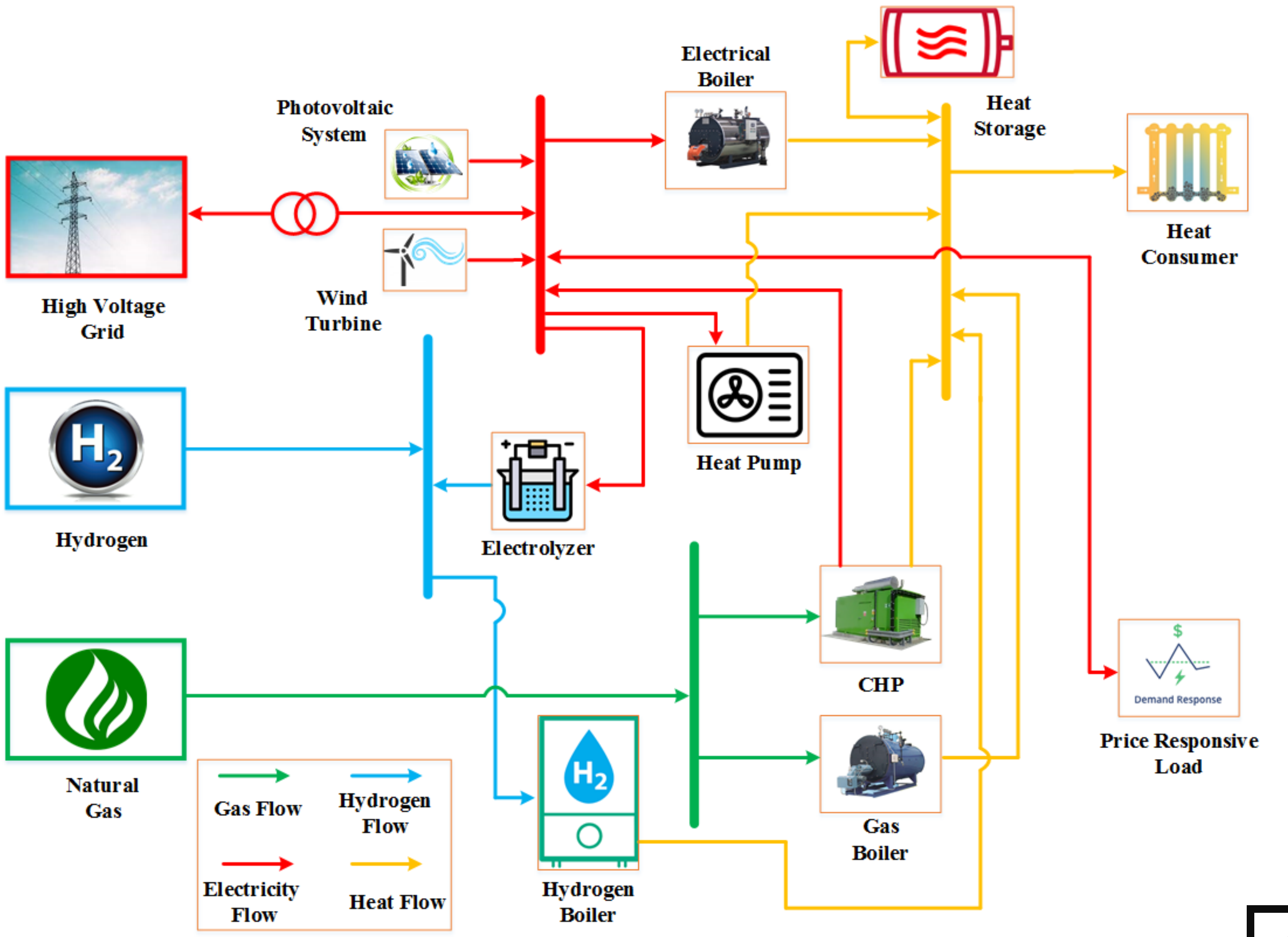
Method of Research…

In a nutshell…

Purpose	Flexibility Improvement of MV-DN (Congestion Management)
Type of Method	Changing generation and consumption Profiles
Type of Incentive	Nodal pricing
Procedure	Curative
Timeframe	After Day-Ahead Market Clearing
Duration	An Hour
Providers of Flexibility	Grid Users
Procurers of Flexibility	Distribution System Operator
Type of Model	Single-Leader-Multiple-Followers game (Stackelberg game)

Method of Research…

- In this model, it is assumed that the medium-voltage distribution grid has been upgraded by decentralized district heating system.
- This case study involves technologies that are able to provide the integration of electricity, gas, hydrogen, and heat.
- Indeed, an integrated energy system has been undertaken for applying the proposed model.
- Electricity, gas, and hydrogen prices are **exogenous** parameters. However, heat price at each dispatch interval can be calculated **locally**. local heat market is also formulated in this model.
- The proposed model assess how incentives in MV-DNs can influence on the local heat price.



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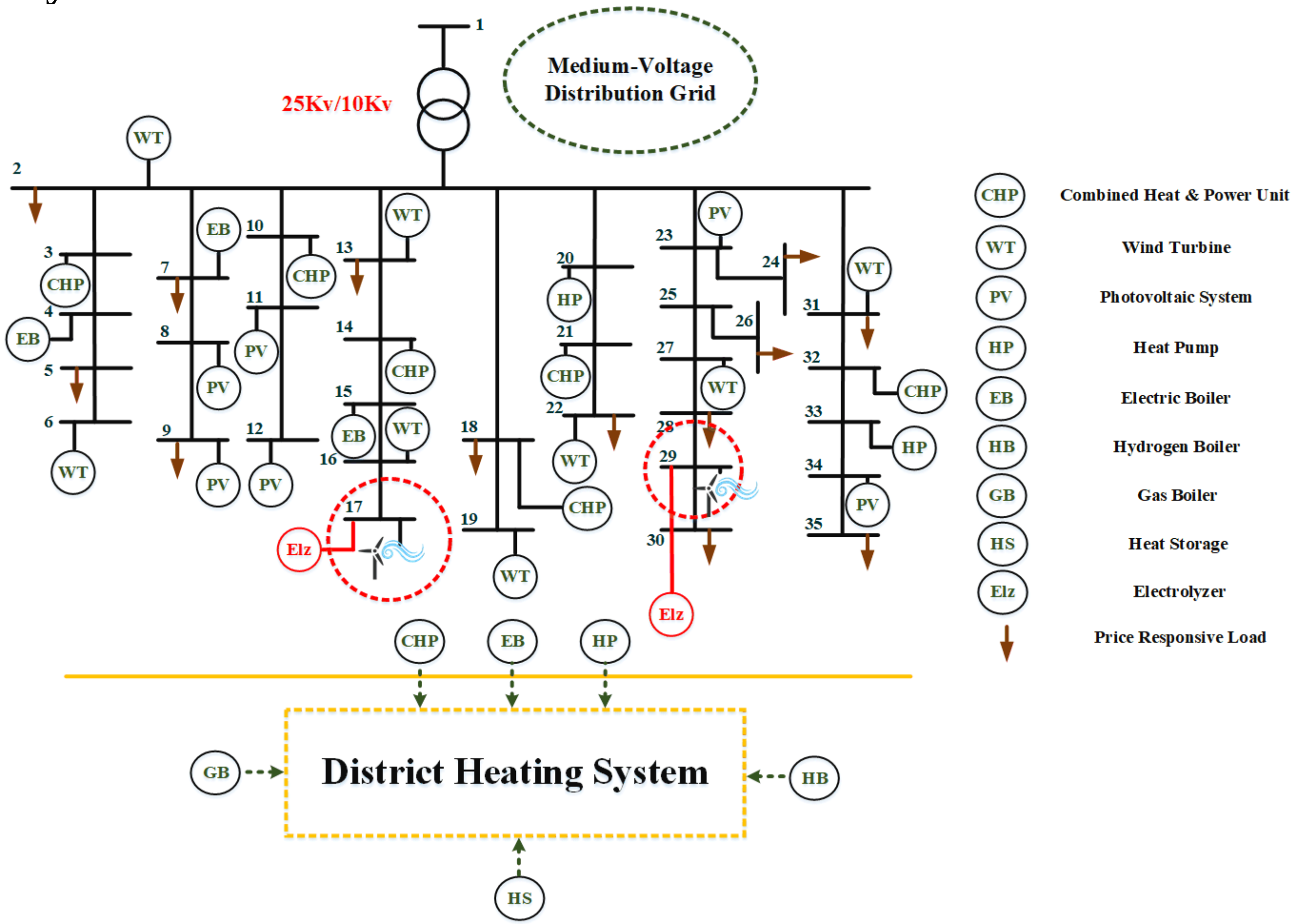
Method of Research…

Case Study



Ref: Coster, E. J. (2010). Distribution grid operation including distributed generation : impact on grid protection and the consequences of fault ride-through behavior. Technische Universiteit Eindhoven.

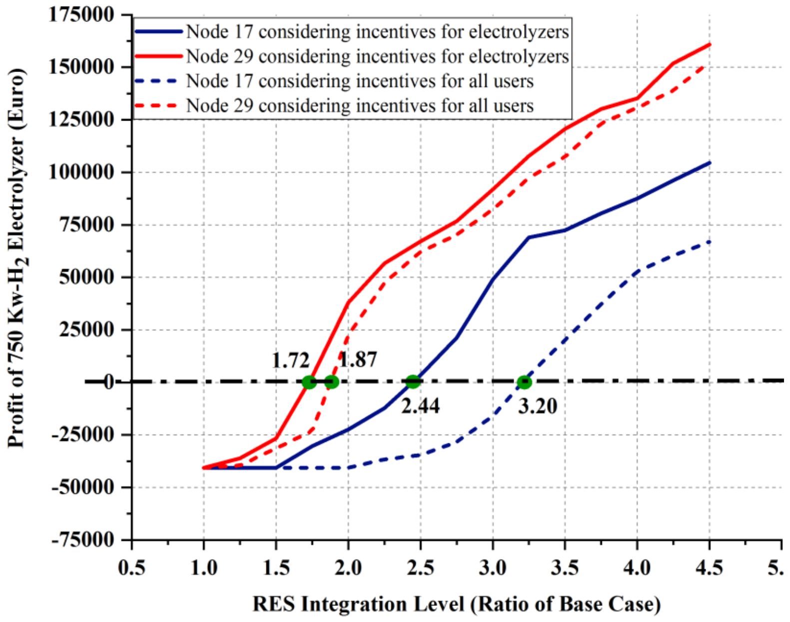
Method of Research…

Assumptions (Base Case):

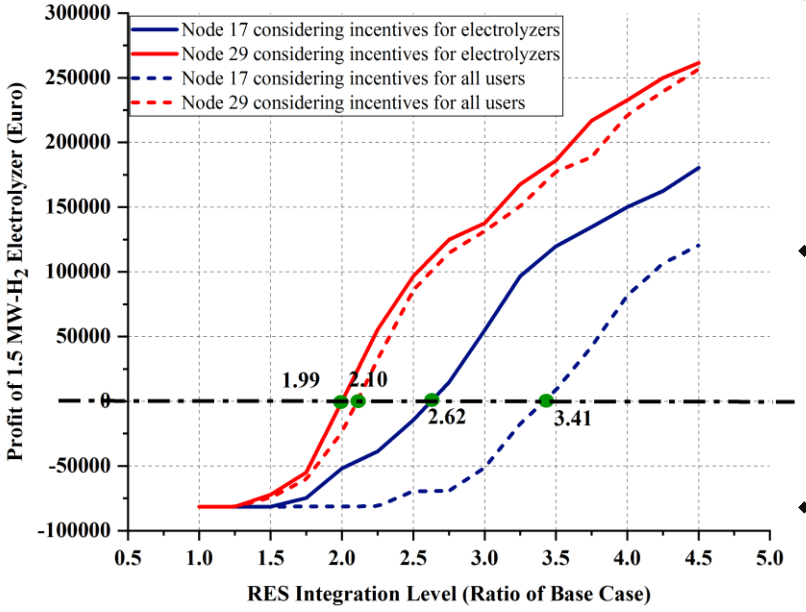
- Total installed capacity of wind turbines is 40 MW. Capacity of each one is 4 MW.
- Total installed capacity of solar panels is 36 MW. Capacity of each one is 6 MW.
- Total renewable generators capacity is 76 MW.
- Total installed capacity of CHP units is 23.95 MW.
- Total installed capacity of electrical boiler is 12.5 MW
- Total installed capacity of heat pump is 9.75 MW
- Average power consumption of price responsive loads is 28.78 MW per hour.
- Average heat demand supplied by district heating is 100 MW per hour.
- Price elasticity for both heat and electric demand is -0.3
- Installed capacity of electrolyzer is assumed to be 0.75 MW and 1.5 MW .
- Two nodes with highest generation curtailment namely 17 and 29 are considered as a location for installing electrolyzers.
- CAPEX for electrolyzer is 1 million Euro per MW.
- CAPEX for Electrical Boiler is 0.6 million Euro per MW.
- Discount rate is 2.5%.

Results

Break-Even Point in Terms of the Needed RES Integration Level



Case A: Capacity of electrolyzer is 0.75MW



Case B: Capacity of electrolyzer is 1.5MW

- Proposing incentives for all users provides **more flexibility** in the grid and consequently higher integration level of RES is demanded for making electrolyzers profitable.
- The **intensity** of the effect of proposing incentives for all users on the break-even point of electrolyzer varies in different locations because of different conditions of the grid's feeders.
- As projected, more RES integration level is required for justifying operation of electrolyzer with higher capacity due to its **higher capital expenditures**.

- Operation of electrolyzer can be profitable when RES integration level is **high enough**.
- Break-even point for electrolyzer at different locations is **not** the same because of **different grid situations** at different locations in terms of consumption and generation patterns, capacity of lines, installed technologies.
- There is a **rise** in the amount of the needed RES integration for making the electrolyzer break even in case of proposing incentives for **all users**.

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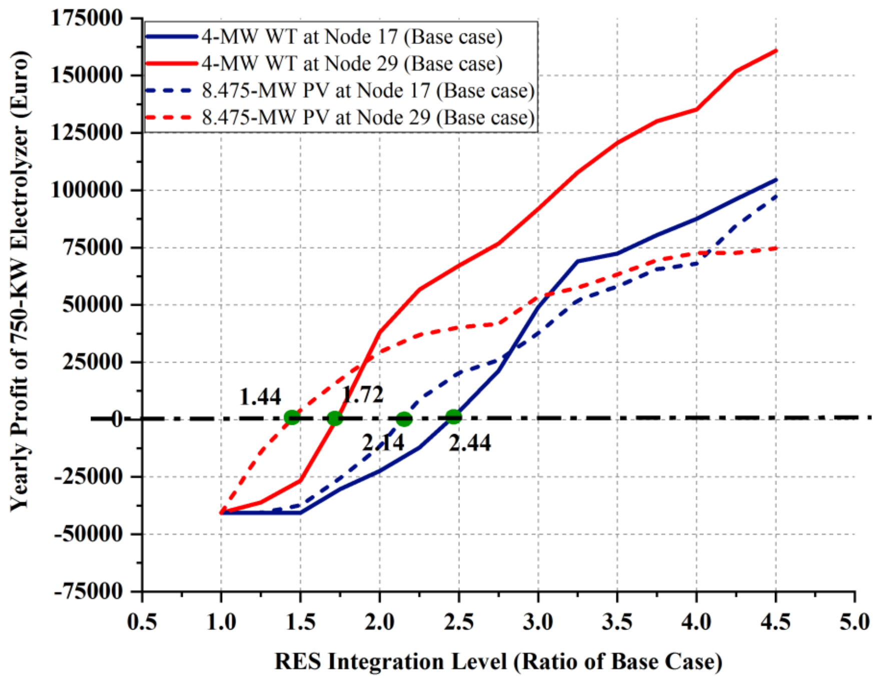
Results…

Effect of Renewable Energy Type on the Break-Even Point of Electrolyzer



At point 1.44: Capacity of installed PV at both nodes: 12.20 MW (Equivalent to 5.76 MW of WT)

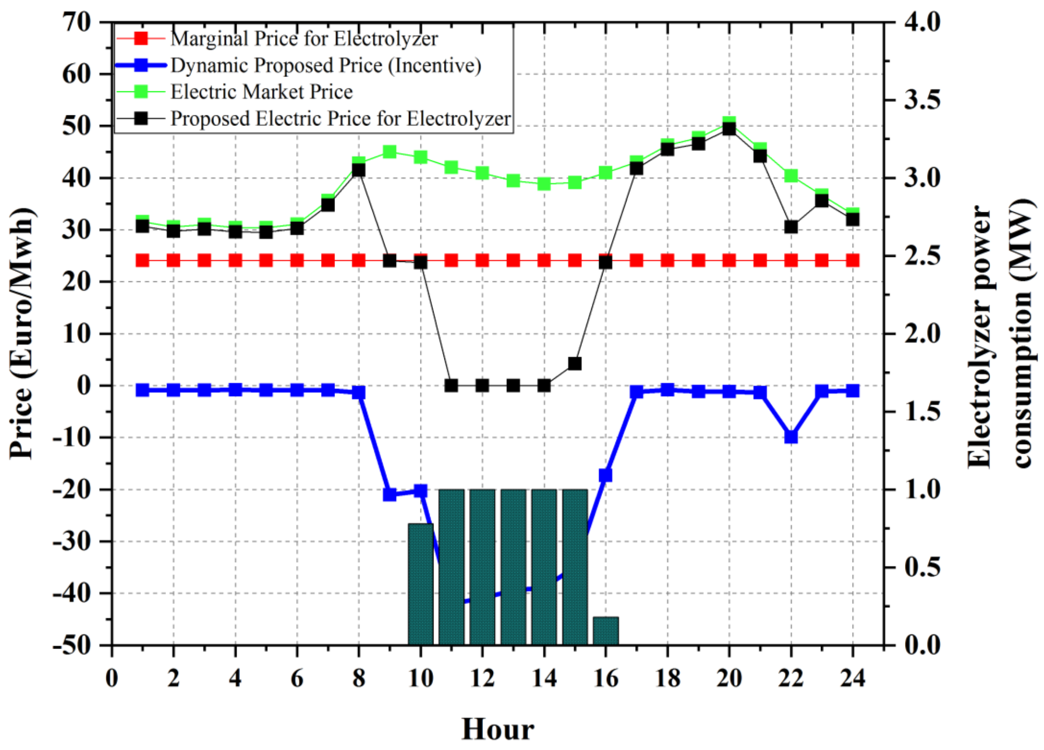
At point 1.72: Capacity of installed WT at both nodes: 6.88 MW At point 2.14: Capacity of installed PV at both nodes: 18.13 MW (Equivalent to 8.56 MW of WT)

At point 2.44: Capacity of installed WT at both nodes: 9.76 MW

- In response of providing **a fair situation** for comparing the effect of different types of renewable resources on the break-even point of electrolyzers, it is assumed that the **average energy production** of them is the same. So, 4-MW WT with average capacity factor of 0,2766 is replaced by 8,475-MW PV with average capacity factor of 0,1306 at the base case.
- At the particular location of the grid, **different types** of renewable energy resources result in different break-even points for electrolyzers.
- The break-even point has declined once photovoltaic system is installed.
- Main reason why break-even point has declined after installing PV systems relates to this fact that **typical day solar irradiance pattern** is different from **wind speed pattern**. The amount of generation curtailment and its frequency are high in case of PV system. Therefore, operation hours of elecrolyzer increase.

Results…

Role of incentives in activating electrolyzer for being operated



- **Without incentives**, electric market price at each dispatch interval is higher than marginal price for electrolyzer. Therefore, it is not practical for electrolyzer to be operated.
- **Negative incentive** during the times grid suffers from **congestion** causes that the proposed electricity price for electrolyzer becomes **lower** than the marginal price. So, operation of electrolyzer is reasonable.

Results…

Number of required operation hours and average proposed dynamic price for electrolyzer at its break-even point

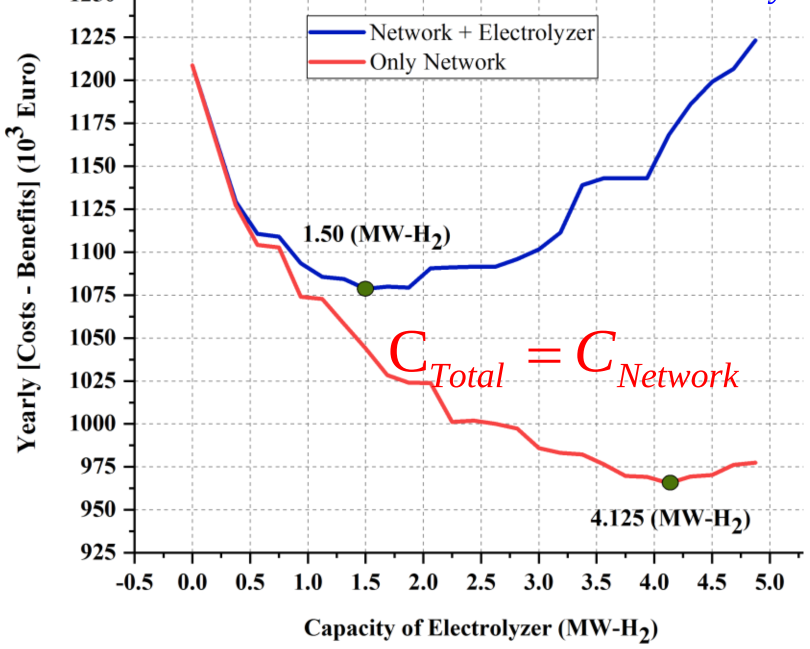
Capacity of Electrolyzer	Proposing Incentives for Other Users	Node	Operation hours	Average Proposed Dynamic Price (Euro/Mwh)
0.75 MW	No	17	1736	-41.15
		29	2683	-34.74
	Yes	17	2808	-30.67
		29	2899	-31.82
1.5 MW	No	17	2530	-36.76
		29	3393	-31.46
	Yes	17	3269	-29.40
		29	3424	-30.66

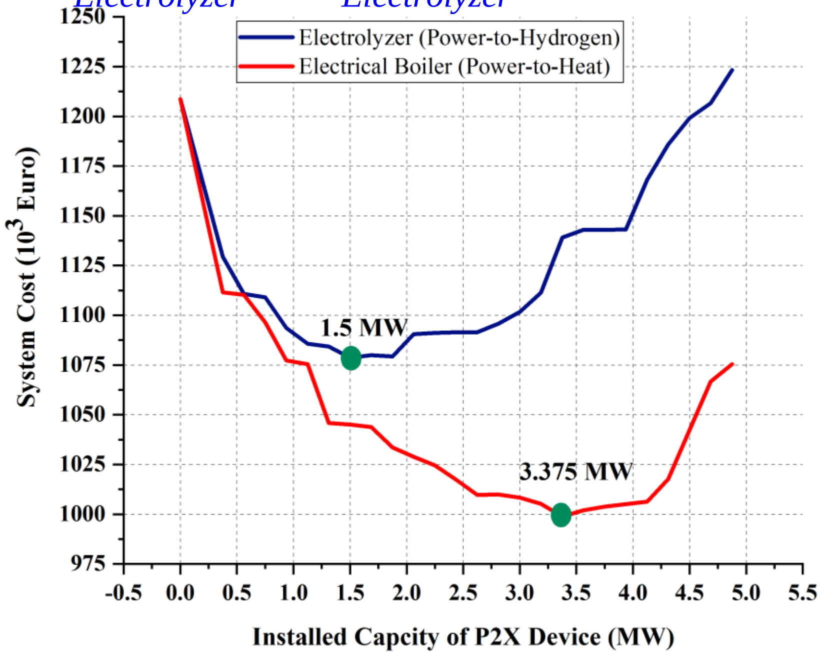
- The **absolute value** of the average proposed dynamic price **is reduced** when incentives are provided for **all users**. Because that providers of flexibility in the grid is **high** and consequently the dynamic price suggested by DNO drops.
- Electrolyzer requires **more operation hours** for being cost-effective in case of receiving **low absolute dynamic price**.
- Electrolyzer with **higher capacity** at the particular node needs **more operation hours** for being profitable.
- The proposed dynamic price **varies** in different nodes of the grid due to different conditions of the grid's feeders.

Results…

Net system cost per different electrolyzer capacity at node 17

$$C_{Total} = [C_{Network}] + [CAPEX_{Electrolyzer} + C_{Electrolyzer} - R_{Electrolyzer}]$$





- Electrolyzer requires **bonus** for operating. This can be provided through making negotiation by network operator.
- Impact of **converting power to heat** on reducing total system cost is more than converting power to hydrogen.
- **Low capital expenditure**, **high efficiency**, and **difference between hydrogen and heat prices** are key factors for justifying why converting power to heat through electrical boiler results in more reduction in system cost.

- Installing electrolyzer **up to a certain extent** can contribute to reduction in the system cost.
- Installing electrolyzer with more capacity although **reduces** generation curtailment cost in the grid, **increases** the net system cost by adding extra cost associated with electrolyzer net yearly cost.
- For the situation with the minimum system cost, the **net cost of electrolyzer** is **positive**. It means that from the investor of electrolyzer's view, it is **not** cost-effective to invest on such technology.

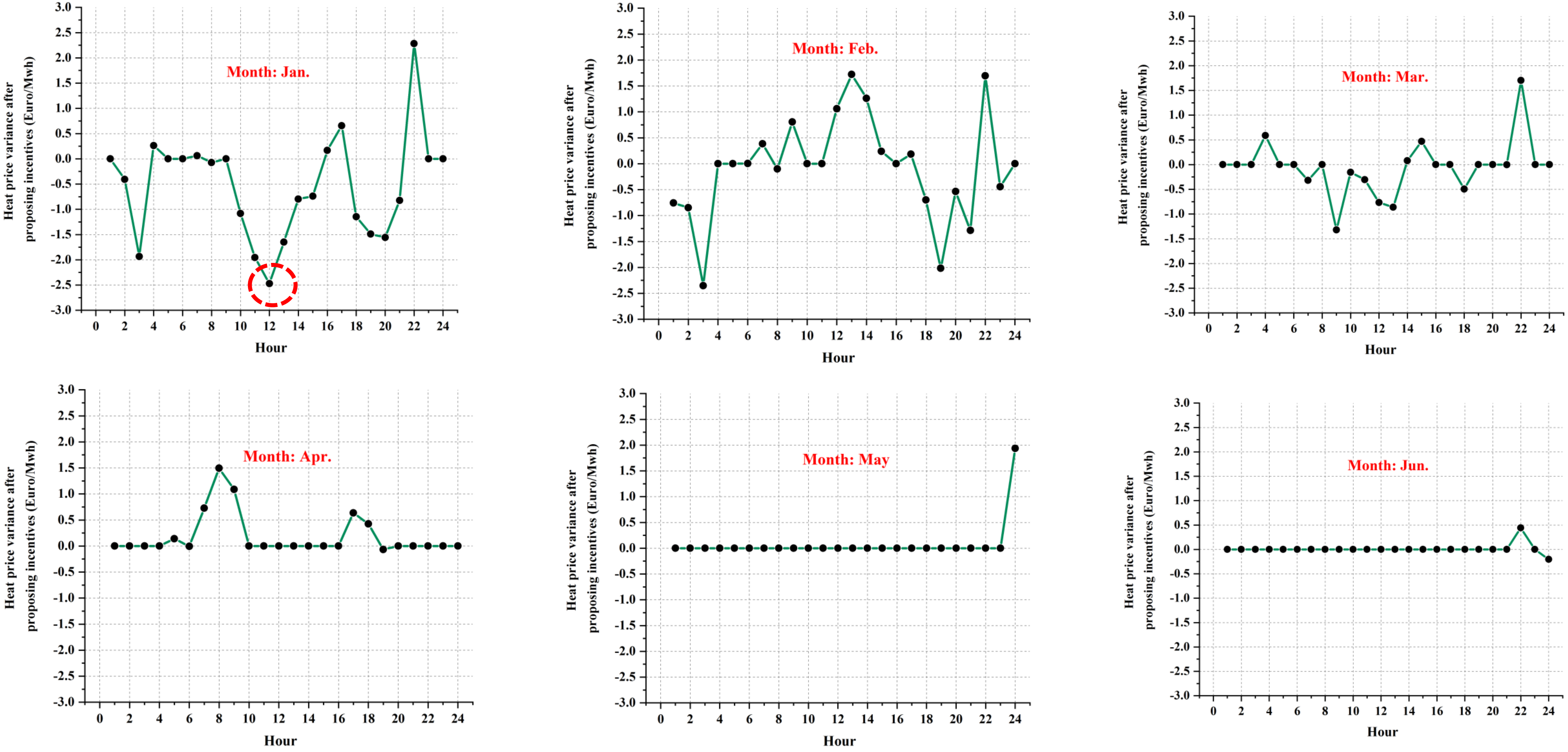
Item	Without Incentive & Without Electrolyzer	With Incentive & Without Electrolyzer	With Incentive & With Electrolyzer	% of Improvement	% of Improvement
Network	-1208.69	-828.34	-560.52	31.460	53.620
CHP Units	617.82	456.57	456.86	-26.100	-26.052
Renewables	13898.59	13898.59	13898.59	0	0
Electric Consumers	18301.79	18933.05	18775.67	3.449	2.589
Electric Boilers	78.35	132.43	120.55	69.021	53.851
Heat Storage	6.48	6.83	6.78	5.368	4.636
Gas Boilers	6832.20	6909.19	6909.39	1.126	1.129
Hydrogen Boilers	35.51	29.74	29.84	-16.250	-15.957
Heat Pumps	1491.19	1513.10	1513.20	1.469	1.475
Heat Consumers	24957.10	24874.31	24873.50	-0.331	-0.334
Electrolyzers	0	0	113.35	-	-
Total	65010.38	65925.50	66137.25	1.407	1.733

Net yearly operation revenue of grid users (1000 Euro)

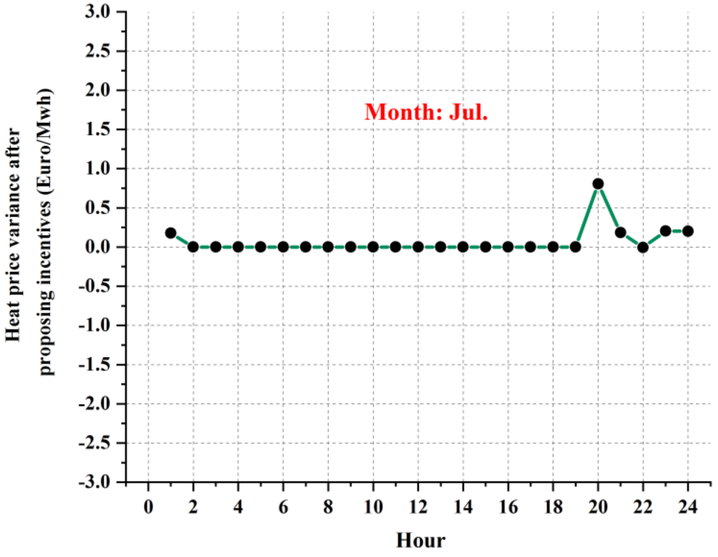
Results…

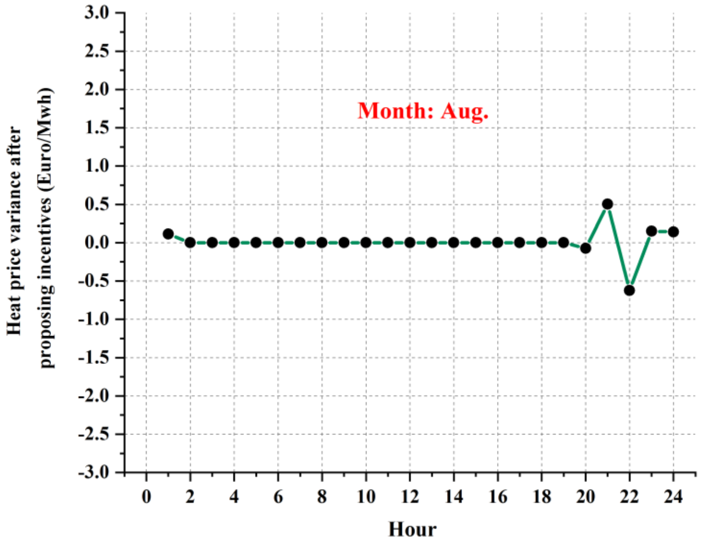
- Network cost comprises of three components. Generation curtailment cost is one of them. Proposing incentives for grid users to change their generation and consumption patterns results in **less generation curtailment** and consequently less operation cost.
- Revenue of CHP units **has decreased** due to the reduction of electricity prices. (Proposed dynamic prices are **negative** in most of times)
- **Arbitrage strategy** of heat storage leads to gain more benefit after proposing incentives. Proposing incentives makes more difference in heat prices during 24 hours.
- Negative dynamic prices result in **less operation cost** of electrical boilers and consequently their revenue increase. This also true for heat pump as well.
- Negative dynamic prices **implicitly** affect on gas boilers revenue. Negative dynamic prices have an influence on heat prices. Average heat price **during operation hours** of gas boilers **has increased**. So, the revenue of gas boiler **has increased**.
- Negative dynamic prices **implicitly** affect on hydrogen boilers revenue. Negative dynamic prices have an influence on heat prices. Average heat price **during operation hours** of hydrogen boilers **has decreased**. So, the revenue of hydrogen boiler **has decreased**.
- Proposing incentives in MV-DN has **a slight effect** on heat consumers revenue. Some times, it causes an increase in heat price and so reduces consumers revenue and some time it leads decrease in heat price and so increases consumers revenue.

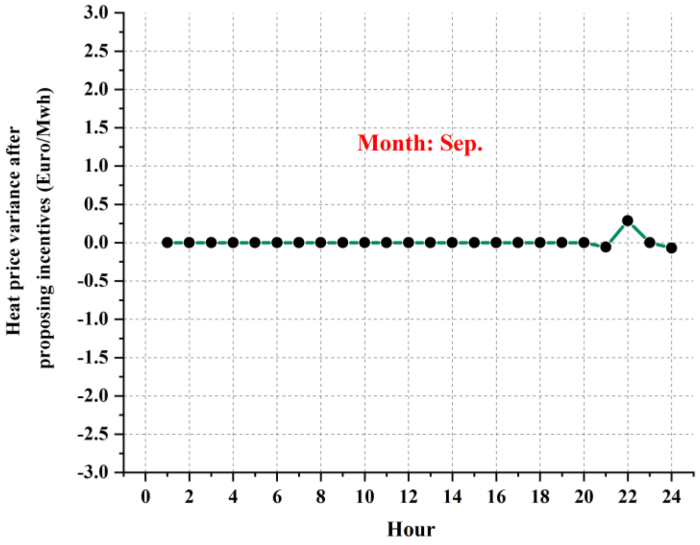
Effect of incentives in MV-DN on heat price:

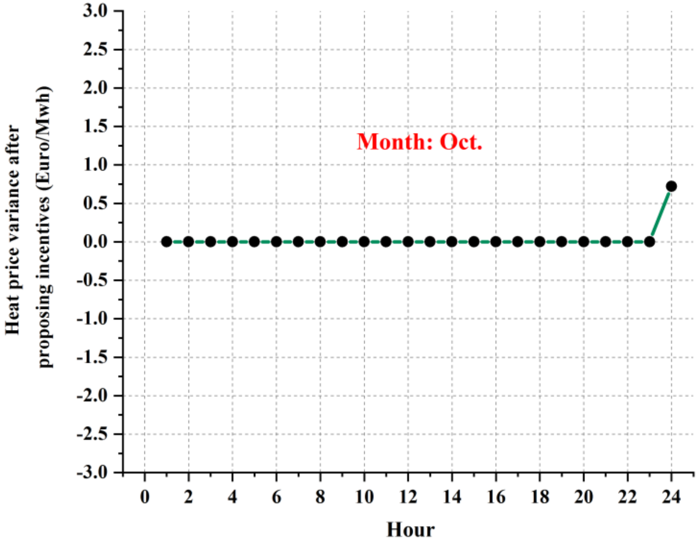


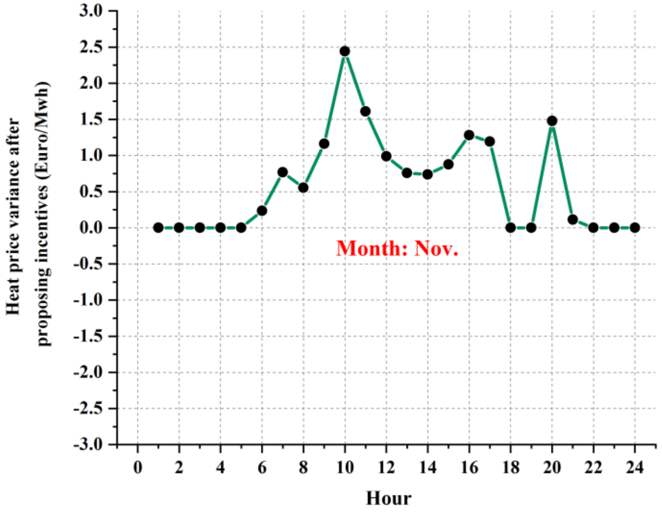
Effect of incentives in MV-DN on heat price:

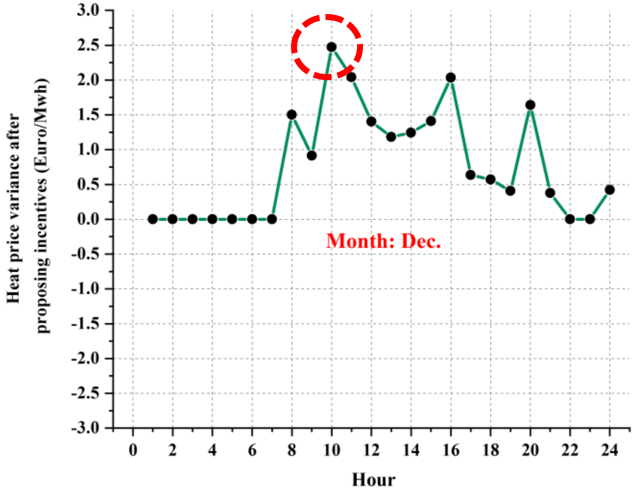












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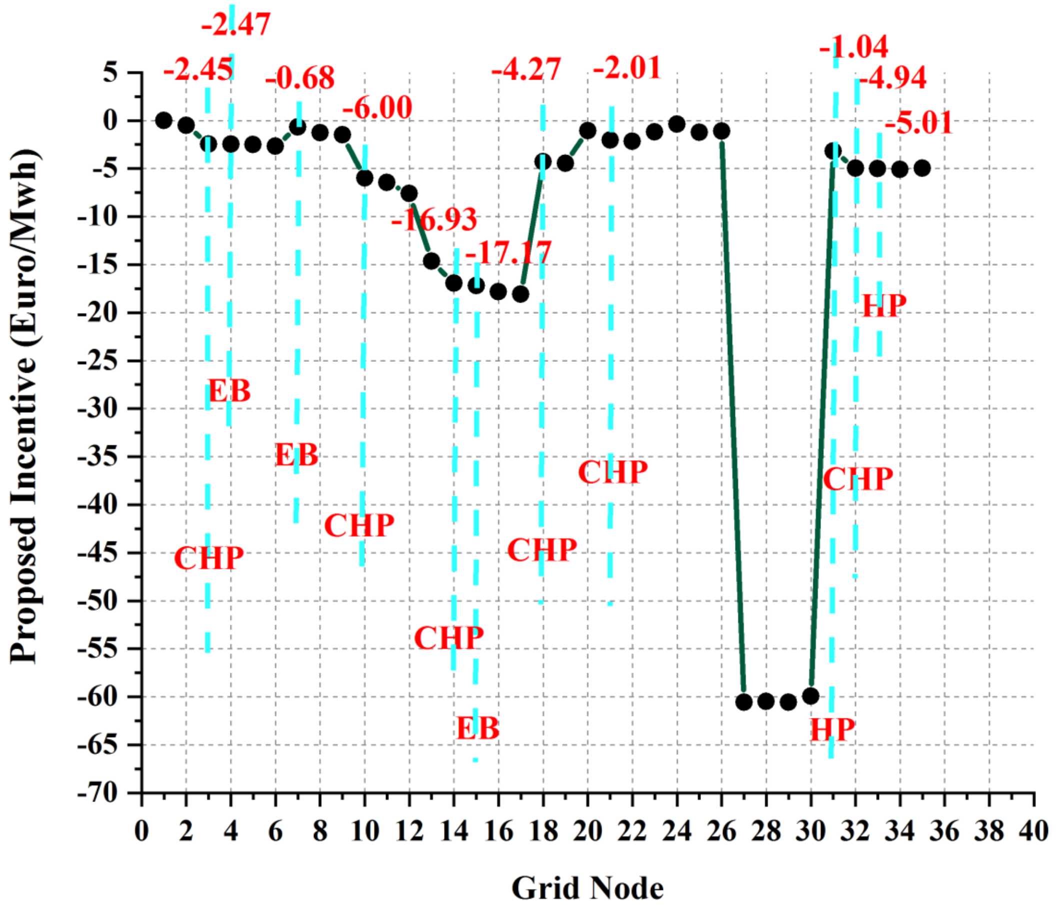
Amount of generated heat power (P.U.)

Technology	Without Dynamic Price	With Dynamic Price	% of an increase in generation
Gas Boiler	1.8333	1.8333	0
CHP Units	0.3592	0.3367	-6.26
Electrical Boilers	0.0063	0.1272	1919.04
Heat Pumps	0.1625	0.1625	0
Heat Storages	0	0	0
Hydrogen Boilers	0.1916	0.1795	-6.31
Total Generation	2.5531	2.6393	3.37

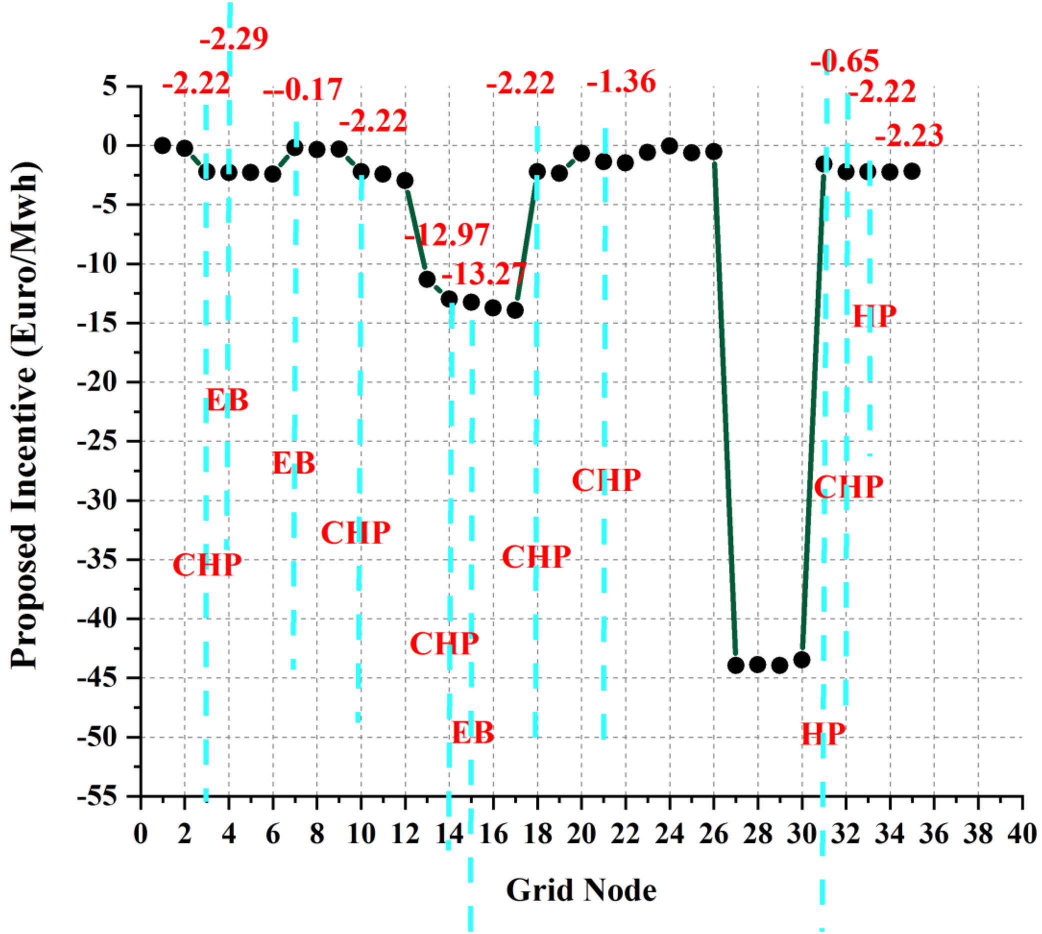
Month: Jan, Hour: 12.00



❖ Electricity Price: 60.57 Euro/Mwh, Hydrogen Price: 50.78 Euro/Mwh, Gas Price: 21.54 Euro/Mwh, Heat Price without Incentive: 60.58 Euro/Mwh, Heat Price with Incentive: 58.11 Euro/Mwh (**Before** proposing incentive, **marginal cost of electrical boiler** determines the heat price and **after** proposing incentives, **marginal cost of hydrogen boiler** determines that.)

Amount of generated heat power (P.U.) Month: Dec, Hour: 10.00 A.M.

Technology	Without Dynamic Price	With Dynamic Price	% of an increase in generation
Gas Boiler	1.8333	1.8333	0
CHP Units	0.3094	0.1806	-41.62
Electrical Boilers	0	0.0410	-
Heat Pumps	0.1625	0.1625	0
Heat Storages	0	0	0
Hydrogen Boilers	0	0	0
Total Generation	2.3053	2.2175	-3.80



❖ Electricity Price: 43.94 Euro/Mwh, Hydrogen Price: 37.00 Euro/Mwh, Gas Price: 13.20 Euro/Mwh, Heat Price without Incentive: 28.19 Euro/Mwh, Heat Price with Incentive: 30.66 Euro/Mwh. Euro/Mwh (**Before** proposing incentive, **marginal cost of CHP units** determines the heat price and **after** proposing incentives, **marginal cost of electrical boiler** determines that.

Conclusion

- Electrolyzers are able to play **positive** role in reducing congestion in the MV-DV in case of receiving incentives.
- From system point of view, dynamic electricity prices as incentives have **positive influence** on improving net operation revenue.
- Developing of electrolyzer in medium-voltage distribution grid for reducing congestion can be cost-effective **when** the integration level of RES is **high enough**.
- Electrolyzers require **more** operation hours in order to be cost-effective when **the number of flexibility providers** increases in the grid.
- The proposed **dynamic price** for the particular electrolyzer reduces when **the number of flexibility providers** increases in the grid.
- A break-even point for electrolyzer in terms of the needed RES integration level **can be varied** in different electrolyzer's installed capacities, locations, and types of renewable energy sources.
- Installing electrolyzer **up to a certain extent** can contribute to reduction in the system cost.

Conclusion

- Despite of proposing dynamic prices, **additional remuneration** is required to maintain an operation of electrolyzer **cost-effective**.
- According to this project's assumption, **converting power to heat** through electrical boiler reduces the system cost **more** than converting power to hydrogen through electrolyzer.
- Proposing incentives in MV-DN can have an influence on local heat prices in **both directions** (Incremental, decremental) in the integrated energy system.

Thank you for your attention.