Stochastic optimization of operation of power to gas included energy hub considering carbon trading, demand response and district heating market

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The presence of new devices with their new technology makes the optimal scheduling of energy hub's operation more complicated and challenging; however, it brings more flexibility. Power to gas as one of the recent types of energy storage that can enable the energy hub in the carbon trading market based on its carbon recycling feature. Participation in the carbon emission trading market can be considered as a suitable option for reducing the operation cost. In this paper, an energy hub included the power to gas technology has been investigated. In addition to the power to gas, the combined heat and power unit beside the gas-powered boiler make the different energy conversion to each other possible. The district heating network among market context has been considered as well as electricity. The demand response program as one of the smart grid's strategies has been employed besides the other control variables of an energy hub. Finally, the uncertainties of problem such as demands, renewable sources production, prices are handled by using a stochastic optimization method. A mixed-integer linear programming formulation has been proposed for the optimization of defined energy hub's operation. The output results demonstrate that added flexibility by participation in the carbon emission trading market and demand response program are capable for 2% reduction of operation cost.

keywords: *Energy hub, Power to gas, Carbon emission market, Demand response, Energy market.*

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NOMENCLATURE

Indices

t Index of hour

t index of Scenario

parameters

S Number of scenarios

ρ_s Probability of each scenario

$\pi^E_{t,s}$ Electricity market price

$\pi^G_{t,s}$ Natural gas market price

$\pi^H_{t,s}$ District heating market price

π^E_{DR} Electrical demand response program cost

π^H_{DR} Thermal demand response program cost

$alpha_s$ Carbon emission market price

$P^{wind}_{t,s}$ Imported electrical power from wind turbine

$P^{E,demand}_{t,s}$ Energy hub's electrical demand

$P^{H,demand}_{t,s}$ Energy hub's heat demand

P^E_{max} Maximum capacity of electrical grid

P^G_{max} Maximum capacity of natural gas grid

P^H_{max} Maximum capacity of district heating grid

P^{input}_{CHP} CHP's input capacity

P^{input}_{boiler} Boiler's input capacity

P^{input}_{PtG} PtG input capacity

η^{EE}_{Trans} Electrical transformer's efficiency

η^{GE}_{CHP} Gas-electricity efficiency of CHP

η^{GH}_{CHP} Gas-heat efficiency of CHP

η^{GH}_{Boil} Boiler's efficiency

η_{Elec} efficiency of electrolyzer

η_{Methan} Methanization procedure's efficiency

$\eta_{Ch,Tank}$ Hydrogen tank charging efficiency

$\eta_{Dis,Tank}$ Hydrogen tank discharging efficiency

LPF^{E}_{up} Upper level of increased electrical demand ratio

LPF^{E}_{down} Upper level of decreased electrical demand ratio

LPF^{H}_{up} Upper level of increased thermal demand

LPF^{H}_{down} Upper level of decreased thermal demand

$Level^{Tank}_{max}$ Maximum capacity of hydrogen tank

$P^{Ch,Tank}_{max}$ Maximum capacity of hydrogen tank charging

$P^{Dis,Tank}_{max}$ Maximum capacity of hydrogen tank discharging

$v_{t,s}$ Wind speed

v^{c}_{in} Cut-in speed of turbine

v^{c}_{rated} Rated speed of turbine

v^{c}_{out} Cut-out speed of turbine

P^{w}_{r} Rated power of turbine

Variables

$P^{E}_{t,s}$ Imported electrical power from grid

$P^{G}_{t,s}$ Imported natural gas from grid

$P^{H}_{t,s}$ Imported thermal power from grid

$P^{E,down}_{t,s}$ Shifted down electrical power by DRP

$P^{E,up}_{t,s}$ Shifted up electrical power by DRP

$P^{H,down}_{t,s}$ Shifted down heat power by DRP

$P^{H,up}_{t,s}$ Shifted up heat power by DRP

$P^{H,loss}_{t,s}$ Energy hub's heat loss

$P^{CHP}_{t,s}$ CHP's input natural gas power

$P^{B}_{t,s}$ Boiler's input natural gas power at hour t period

$P^{E,PtG}_{t,s}$ Input power of PtG

$P^{Meth}_{t,s}$ Total produced natural gas by PtG

$P^{Meth,In}_{t,s}$ Provided Natural gas by PtG to hub

$P^{GS}_{t,s}$ Sold natural gas by PtG

$I^{E,up}_{t,s}$ Binary variable representing electrical demand shifting up

$I^{E,down}_{t,s}$ Binary variable representing electrical demand shifting down

$I^{H,up}_{t,s}$ Binary variable representing heat demand shifting up

$I^{H,down}_{t,s}$ Binary variable representing heat demand shifting down

$P^{H,Elec}_{t,s}$ Produced hydrogen by electrolyzer

$P^{H,Methan}_{t,s}$ Input hydrogen energy of methanization

$P^{Ch,Tank}_{t,s}$ Charging power of hydrogen tank

$P^{Dis,Tank}_{t,s}$ Discharging power of hydrogen tank

$Level^{Tank}_{t,s}$ hydrogen tank energy level

$I^{Ch,Tank}_{t,s}$ Binary shows the charging status of hydrogen tank

$I^{Dis,Tank}_{t,s}$ Binary shows the dis charging status of hydrogen tank

Acronyms

PtG Power to gas

DRP Demand response program

CHP Combined heat and power

1. INTRODUCTION

Progressive condition of energy types converters have strengthened the energy hub's concept which it has been declared as the framework of future energy systems [1]. The interdependencies which have been made possible by these technologies bring out optimization opportunities that can be utilized for different goals [2]. In recent years, different architecture of energy hubs has been introduced and investigated. One of the recent practical technologies of energy conversion filed is the power to gas (PtG) technology which has brought particular flexibility and capability into energy management's optimization studies with its interesting features [3]. PtG is one of main proposed solutions for renewable curtailment of high renewable penetrated power systems [4]. Near to 50 practical PtG have been implemented among Europe for investigation of its operation [5]. Therefore, optimization of energy hubs includes PtG considering the modern energy systems issues such as demand response, carbon and energy markets can be posed as one of the main challenges of these energy hubs.

A. Literature review

The energy hub concept's research potential has absorbed the energy field's researchers for investigation of various outlooks of issue [6]. Presenting the new mathematical models for energy hubs [7], finding optimum architecture of hub [8, 9], optimal energy flow in widespread energy networks [10, 11] and scheduling of hub are the most attractive subjects among this filed for researchers.

The modern energy systems' features and nature are different from traditional versions. The renewable energy resources' penetration has been intensified in new electrical networks [12]. Novel functions such as demand response programs (DRP) [13, 14] have been announced as permanent functions of distribution networks. All of these issues besides the deregulation of electrical networks prepare the challenging condition for the optimization of energy hubs in the distribution network scale. In addition, the presence of new technologies like PtG has made the operation problem more complicated.

Utilization of diverse optimization methods, functions and assumptions of different conditions are the main contributions of literature among the energy hub's operation's subject. Reference [15] novelty in the finding optimal scheduling of hub is using robust technique. Reference [16] investigates the energy management of an industrial case study. In this study, different components of a energy management problem such as consumer and distribution company have been analyzed by the energy hub concept. Answering to question of how an energy hubs should participate in a competitive market has been done in [17]. Reference [18] propose that electrical vehicle can play the role of an energy storage system to neutralize the variable generation of a wind turbine. The hub operation's investigation in this study is under the deterministic condition without considering any uncertainty. In the continuation of optimal scheduling of the energy hub among the electricity market, [19] carries out the investigation of the optimal bidding problem of energy hub in a day ahead market. This reference's method for handling the problem's uncertainties is stochastic programming. The reference [20] has studied the application of a multi-carrier energy system concept in the Canadian community. It has done an optimization with multi objectives of economic and environment. The assessment of energy hub operation sensitivity according to electricity price uncertainty has been done in [21]. Reference [22] presents a linear single objective optimization for energy management of coordinated energy hubs among different networks of electricity, natural gas and district heating. The stochastic method has been utilized for handling the uncertainties of the problem in this study. The researchers in [23] investigate the impact of the presence of an energy hub element in the energy management of smart distribution networks. The utilized strategy for energy management of the distribution network in this study is demand response which utilized the brought up flexibility by energy hubs in both electrical and thermal energy demand. The study of co-optimization of planning & operation of energy is available in [24]. The main focus of authors in this study is sizing of energy storage among optimization of energy hub's operation which has been done using two-stage robust method. In [25] an energy hub based microgrid has been proposed for energy management of electrical and thermal energy resources.

In recent years, penetration of PtG storage systems has been increased [26]. This technology has provided the opportunity of storing electricity as natural gas carried using chemical procedures [27]. The optimal operation of PtG included energy hub with consideration of hydrogen as demand was investigated by [28]. The [29] has presented the economic evaluation of PtG based on the energy hub idea. The [30] contributed to the simultaneous optimization of PtG and combined cycle power plant based on the energy hub concept. The methods of solving the problem of non-dispatchable generation of renewables have been studied in [31] which has proposed the utilization of a combination of gas-powered turbine and PtG.

In addition, posing new energy markets have brought more complexity to energy management problems. District heating network has been proposed as a serious novel energy network in new design of energy systems which can be implemented in a local area scale. Investigation of these new energy systems can be found in literature [32–34]. The district heating network has come to phase of the deregulated energy system with its own market. Different thermal energy producers beside the consumers who appeal to utilize district heating network for meeting their thermal demand has brought out this energy network to price bidding environment in countries such as Finland and Sweden [32]. The progress of the thermal energy market has cause to extend this market up to single-family houses [33].

B. Novelty and contributions

Presence of new functions and condition besides the novel energy technologies declare the necessity of energy management studies which can be done with economic targets.The existence of PtG among the energy hub's structure enables the hub to participate in the carbon emission market. Participation in this market as a new income source for the hub influence the hub's optimal operation point. To find the optimal values of control variables such as demand response strategies or devices setting, this new device should be modeled in the context of energy hub.

In this paper, the short-term optimal scheduling of an energy hub is presented. The assumed energy hub includes the PtG facility beside the other energy conversion devices. The optimization of the operation of an energy hub is carried out considering the heating and electrical energy markets. Optimization of the hub's strategies for participating in demand response programs as a feature of smart energy systems is another option that has been accounted for this paper. Due to the carbon reduction capability of PtG technology, the participation of energy hub in the carbon emission trading market has been made possible which will be studied. Finally, for handling the problem's uncertainties, the stochastic optimization method has been employed to achieve more practical and reliable results.

2. ENERGY HUB MODEL

Based on the possibility of the various architecture of energy hubs, the design of hubs should be explored in the energy hub's optimal operation studies, firstly. The assumed hub in this paper-as shown in Fig. 1 has three input energy carriers of electricity, natural gas and district heating where the outputs are electrical demand and thermal energy demand. The inside devices of the hub are CHP, gas-powered boiler, transformer and PtG. Both electrical and thermal demand response has been enabled for this hub. The defined duties of the assumed hub are meeting the demands and synthetic natural gas to network with it has been made by PtG. The assumed energy hub includes the wind turbine which provides clean and cheap electricity for hub.

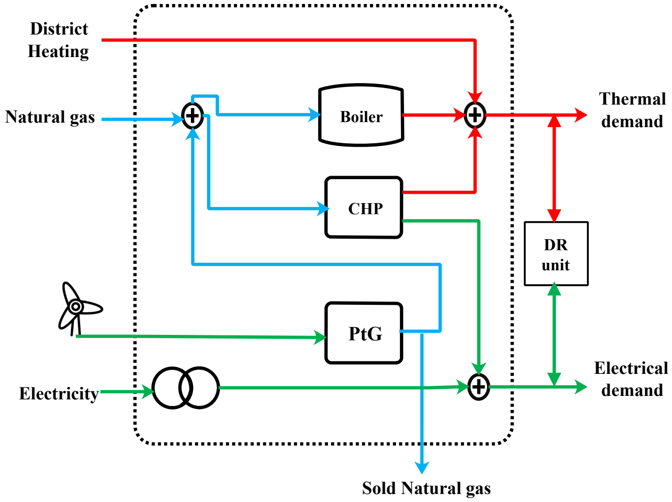

Fig. 1. Assumed energy hub's schematic.

3. PROBLEM FORMULATION

A. Objective function

The goal of optimization of the energy hub's operation in this paper is economical. The objective function of this optimization problem is formed from cost and income terms. The main cost source of energy hub is the cost of imported energy from external resources. Imported electricity, natural gas and district heating which have been mentioned by $cost_E$, $cost_G$, $cost_H$ in the objective function, respectively. Smart grid functions cost has been declared by $cost_{EDRP}$ and $cost_{TDRP}$ which belong to electrical network and district heating network, respectively. Finally, the incomes of the system have been appeared as the objective function with a negative sign. The system's income sources are sold natural gas by PtG technology and input profit by participation in the carbon emission markets which have been dedicated with Inc_{NGS} and Inc_{CT}, respectively.

$$Objective function = \sum_{s=1}^{S} \rho_s \sum_{t=1}^{24} \{cost_E + cost_G + cost_H + \tag{1}$$

$$cost_{EDRP} + cost_{TDRP} - Inc_{NGS} - Inc_{CT}\}$$

Where:

$$cost_E = \pi^E_{t,s} P^E_{t,s} \tag{2}$$

$$cost_G = \pi^G_{t,s} P^G_{t,s} \tag{3}$$

$$cost_H = \pi^H_{t,s} P^H_{t,s} \tag{4}$$

$$cost_{EDRP} = \pi^E_{DR}(P^{E,down}_{t,s} + P^{E,up}_{t,s}) \tag{5}$$

$$cost_{TDRP} = \pi^H_{DR}(P^{H,down}_{t,s} + P^{H,up}_{t,s}) \tag{6}$$

$$Inc_{NGS} = \pi^G_{t,s} P^{GS}_{t,s} \tag{7}$$

$$Inc_{CT} = \alpha_s P^{Meth}_{t,s} \tag{8}$$

B. Constraints

B.1. Energy balance constraints

Energy balance law should be satisfied for each kind of energy carrier based on both time and scenario indices. This law's equality can be converted to inequality in thermal energy because of the possibility of loss. The equations of energy balance constraint in the energy hub have been written as follows:

$$P^{E,demand}_{t,s} - P^{E,down}_{t,s} + P^{E,up}_{t,s} = \tag{9}$$

$$[\eta^{EE}_{Trans} P^E_{t,s}] + [\eta^{GE}_{CHP} P^{CHP}_{t,s}]$$

$$P^{H,demand}_{t,s} - P^{H,down}_{t,s} + P^{H,up}_{t,s} + P^{H,loss}_{t,s} + = \tag{10}$$

$$[\eta^{GH}_{CHP} P^{CHP}_{t,s}] + [\eta^{GH}_{Boil} P^B_{t,s}] + P^H_{t,s}$$

$$P^G_{t,s} + P^{Meth,In}_{t,s} = P^{CHP}_{t,s} + P^B_{t,s} \tag{11}$$

$$P^{Meth}_{t,s} = P^{Meth,in}_{t,s} + P^{GS}_{t,s} \tag{12}$$

As it is observable in Eq. (9) the equality of electrical production with electrical demand has been integrated by the degree of freedom of electrical DRP. Similar to electricity, the energy balance law has been indicated for district heating and natural gas. It is worth to be mentioned, the equality of (10) can be written as inequality without loss's term as discussed above.
In addition, Eq. (11) shows the possibility of feeding gas-powered devices of the hub by output gas of PtG beside the natural gas network, where, Eq. (12) accounts for demonstrating different parts of output gas of PtG.

B.2. Technical constraints

Considering the capacity constraints of physical components of the energy hub, make our optimization results more practical and applicable. Ignoring the capacities may bring us settings that can not be utilized in the real. Eqs. (13) to (18) are for this aim.

$$0 \leq P^E_{t,s} \leq P^E_{max} \tag{13}$$

$$0 \leq P^H_{t,s} \leq P^H_{max} \tag{14}$$

$$0 \leq P^G_{t,s} \leq P^G_{max} \tag{15}$$

$$0 \leq P^{CHP}_{t,s} \leq P^{input}_{CHP} \tag{16}$$

$$0 \leq P^B_{t,s} \leq P^{input}_B \tag{17}$$

$$0 \leq P^{E,PtG}_{t,s} \leq P^{wind}_{t,s} \tag{18}$$

B.3. Electrical demand response program constraints

In smart energy systems, the demands are active in contrast to traditional systems that were passive. The load level flexibility is the option of demands for participation in bi two side decisions of an electrical network. This issue which has been named as demand response can be implemented with different mathematical models [35, 36]. The relations (19) to (22) are the load shifting model of demand response. Among this model, Eq. (19) indicates that decreased energy consumption during the specified optimization time periods should be compensated by increasing the power during other optimization time periods. In other words, a consumer just can shift its load and the total amount of consumed energy is unchangeable. The consumers have these limitations that can not change its power level more that a predefined value as shown in Eqs. (20) and (21). For preventing of occurring meaningless results, the positive and

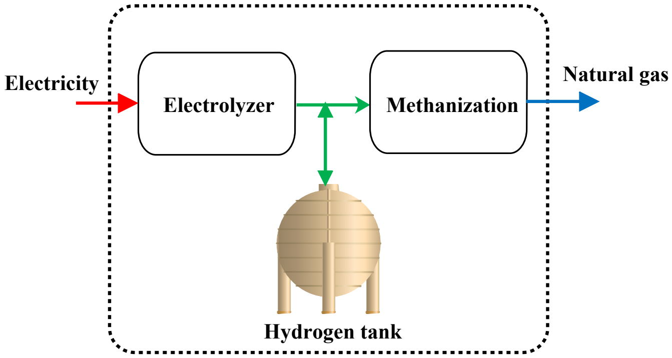

Fig. 2. Assumed PtG model.

negative load shifting at the same time has been stopped by Eq. (22) .

$$\sum_{t=1}^{24} P_{t,s}^{E,down} = \sum_{t=1}^{24} P_{t,s}^{E,up} \tag{19}$$

$$0 \leq P_{t,s}^{E,up} \leq LPF_{up}^{E} P_{t,s}^{E,demand} I_{t,s}^{E,up} \tag{20}$$

$$0 \leq P_{t,s}^{E,down} \leq LPF_{down}^{E} P_{t,s}^{E,demand} I_{t,s}^{E,down} \tag{21}$$

$$0 \leq I_{t,s}^{E,down} + I_{t,s}^{E,up} \leq 1 \tag{22}$$

B.4. Thermal demand response program constraints

The thermal DRP model has been re-written based on electrical DRP as follows:

$$\sum_{t=1}^{24} P_{t,s}^{H,down} = \sum_{t=1}^{24} P_{t,s}^{H,up} \tag{23}$$

$$0 \leq P_{t,s}^{H,up} \leq LPF_{up}^{E} P_{t,s}^{H,demand} I_{t,s}^{H,up} \tag{24}$$

$$0 \leq P_{t,s}^{H,down} \leq LPF_{down}^{H} P_{t,s}^{H,demand} I_{t,s}^{H,down} \tag{25}$$

$$0 \leq I_{t,s}^{H,down} + I_{t,s}^{H,up} \leq 1 \tag{26}$$

B.5. PtG model

Because of the existence of different types of PtG technologies, first of all, the figure of the assumed PtG device has been indicated in Fig. 2. As it is observable in this figure, the input electricity is converted to hydrogen by electrolyzer, then produced hydrogen can be stored in hydrogen tank or enter to mechanization procedure for converting to natural gas form. The following relations model the discussed PtG.

$$P_{t,s}^{H,Elec} = P_{t,s}^{E,PtG} \eta_{Elec} \tag{27}$$

$$P_{t,s}^{Meth} = P_{t,s}^{H,Methan} \eta_{Methan} \tag{28}$$

$$P_{t,s}^{H,Methan} = P_{t,s}^{H,Elec} + P_{t,s}^{Ch,Tank} - P_{t,s}^{Dis,Tank} \tag{29}$$

$$Level_{t,s}^{Tank} = Level_{t-1,s}^{Tank} + (P_{t,s}^{Ch,Tank} \eta_{Ch,Tank}) - (P_{t,s}^{Dis,Tank} / \eta_{Dis,Tank}) \tag{30}$$

$$0 \leq Level_{t,s}^{Tank} \leq Level_{max}^{Tank} \tag{31}$$

$$P_{t,s}^{Ch,Tank} \leq I_{t,s}^{Ch,Tank} P_{max}^{Ch,Tank} \tag{32}$$

$$P_{t,s}^{Dis,Tank} \leq I_{t,s}^{Dis,Tank} P_{max}^{Dis,Tank} \tag{33}$$

$$I_{t,s}^{Dis,Tank} + I_{t,s}^{Ch,Tank} \leq 1 \tag{34}$$

Where, (27) and (28) models the electrolyzer and mechanizations procedures energy loss. The (29) shows the hydrogen carrier energy balance inside the PtG box. The modeling of hydrogen tank (energy balance, charging and discharging constraints) have been demonstrated in (30) to (34).

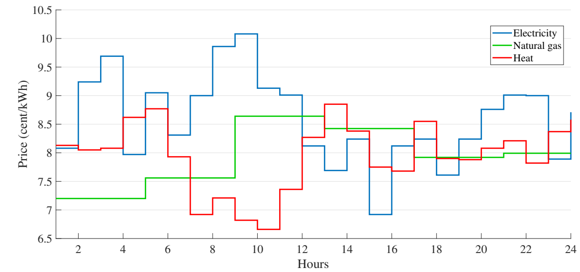

Fig. 3. Assumed energy markets prices.

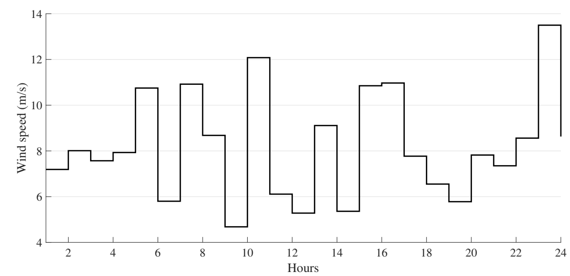

Fig. 4. Wind speed.

B.6. Wind turbine constraint

The third degree relation between the generation of the wind turbine and wind speed can be linearized as demonstrated in following [37]:

$$P_{t,s}^{wind} = \begin{cases} 0 & if\ v_{t,s} \leq v_{in}^{c}\ or\ v_{t,s} \geq v_{out}^{c} \\ \frac{v_{t,s} - v_{in}^{c}}{v_{rated}^{c} - v_{in}^{c}} P_{r}^{w} & if\ v_{in}^{c} \leq v_{t,s} \leq v_{rated}^{c} \\ P_{r}^{w} & if\ \ v_{rated}^{c} \leq v_{t,s} \leq v_{out}^{c} \end{cases} \tag{35}$$

4. SIMULATION RESULTS

A. Case studies & simulation data

The impact of participation in the carbon trading market and the implementation of demand-side management on the scheduling of an energy hub was demonstrated by declaring the results of two case studies. The mentioned cases have been represented as follows:

Case 1: Optimization of energy hub operation without considering demand responses and carbon market.

Case 2: Optimization of energy hub operation considering demand responses and carbon market.

Simulation parameters and settings are presented in the following. The electricity, heating and gas market average prices are accessible in Fig. 3 [38]. The wind speed basic data has been illustrated in Fig. 4 [38]. Finally, the carbon emission market price during different scenarios has been indicated in Fig . 5 [39] where the other simulation parameters can be found in Table 1 (the [38] has used for these parameters) . It is worth mentioning that the scenario generation for each uncertain parameter has been done using the Monte Carlo method with the same probability.

B. Results & discussions

In the first step, the comparison of energy hub's operation during two defined case studies have been presented in Table 2.

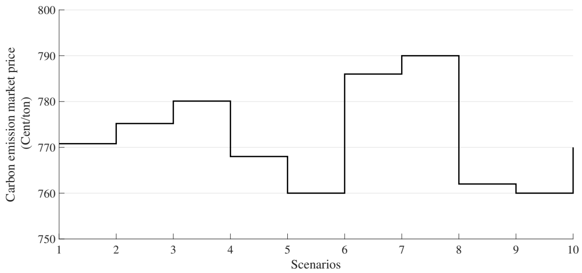

Fig. 5. Carbon emission price.

Table 1. Simulation parameters

Parameter	Amount	Parameter	Amount
S	10	π_{DR}^{E} (cent)	0.5
π_{DR}^{H} (cent)	0.5	P_{max}^{E} (MW)	2
P_{max}^{G} (MW)	1	P_{max}^{H} (MW)	0.5
P_{CHP}^{input} (kW)	500	P_{boiler}^{input} (kMW)	300
P_{PtG}^{input} (kW)	500	η_{Trans}^{EE}	0.98
η_{CHP}^{GE}	0.4	η_{CHP}^{GH}	0.35
η_{Boil}^{GH}	0.85	η_{Elec}	0.6
η_{Methan}	0.85	$\eta_{Ch,Tank}$	0.95
$\eta_{Dis,Tank}$	0.95	LPF_{up}^{E}	0.25
LPF_{down}^{E}	0.25	LPF_{up}^{H}	0.25
LPF_{down}^{H}	0.25	$Level_{max}^{Tank}(kWh)$	500
$P_{max}^{Ch,Tank}$ (kW)	375	$P_{max}^{Dis,Tank}(kW)$	375
v_{in}^{c} (m/s)	4	v_{rated}^{c}(m/s)	10
v_{out}^{c} (m/s)	22	P_{r}^{w} (kW)	600

Table 2. Energy hub's operation cost ($)

	Case 1	Case 2
Electricity cost	1632.80	1596.17
Natural gas cost	228.81	272.71
District heating cost	864.17	879.45
DRP cost	0	22.50
Carbon trading benefit	0	10.07
Natural gas selling	182.22	263.15
Total	2543.56	2497.61

As it is observable, the demand response and participation in carbon trading market are capable to reduce the operation cost about 2% by adding more flexibility to system's operation.The results show the tendency of optimal operation point to selling gas more than the situation in which there is no carbon market, because, the carbon emission trading market is another economic attractiveness for utilization of mechanization part of PtG. DRP is beneficial for the system by adjusting the demand level in the optimal condition. Changing the demand level form its basic condition has been shown in Figs. 6 and 7.
It should be mention that the reported result is for 5^{th} scenario of stochastic investigation. The capability of increasing or decreasing the demand line up to 25%, helps the system to resist against the energy markets price's fluctuations and neutralize them.

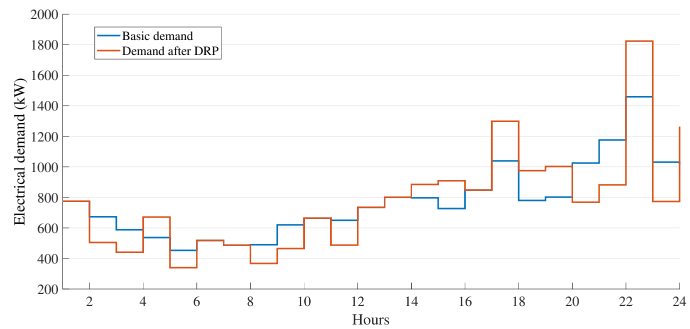

Fig. 6. Electrical demand (Scenario 5).

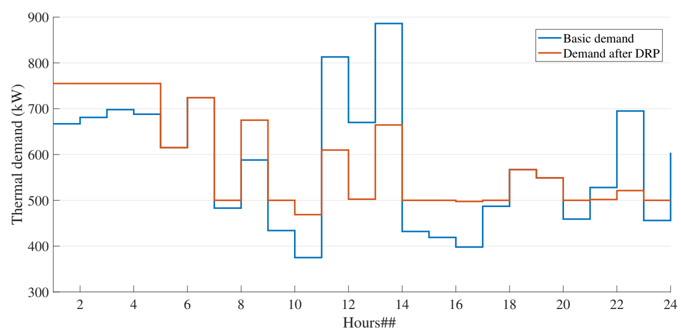

Fig. 7. Thermal demand (Scenario 5).

Power to gas as one of components of an energy hub plays an important role in its operation. The sold natural gas to network beside the participation in the carbon trading market is the activities of this component. Fig. 8 demonstrates the sold natural gas during the optimization period. The hydrogen tank's operation has been indicated in Fig. 9. As it can be interfered, the hydrogen tank is utilized as much as possible to sell the natural gas at its peak price. In addition, due to this fact that the PtG is only fed by the wind turbine, its operation is completely affected by it and its non-constant generation.

Figures 10 and 11 show how the electrical demand and thermal demand are provided by different resources. The difference of produced energy and basic demand in both carriers have been occurred because of the existence of DRP.

Finally, Table 3 indicates the role of PtG in internal gas provision. Based on the structure of the energy hub the PtG can transfer its produced gas into gas-fired components of hub such as CHP of the boiler. The results -as it is observable- show this provision during various hours and scenarios. This provision occurs when the price per KWh of produced gas by PtG after consideration of procedure's efficiency is lower than natural gas grid's price.

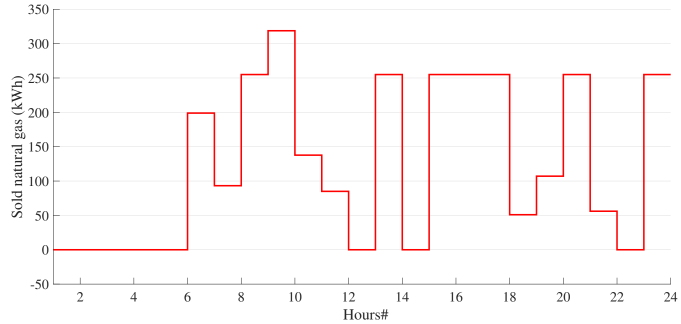

Fig. 8. Sold natural gas (Scenario 5).

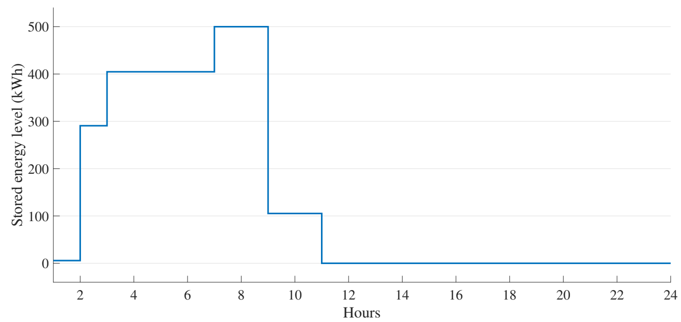

Fig. 9. Hydrogen tank energy level (Scenario 5).

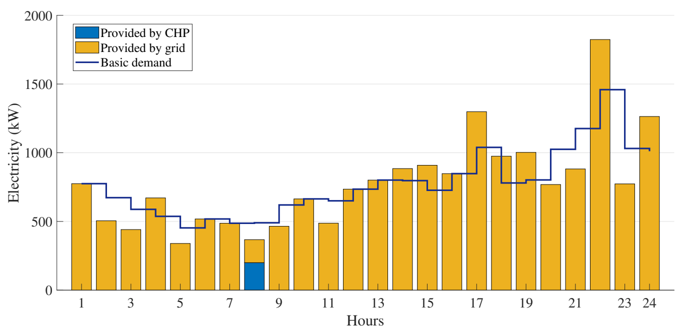

Fig. 10. Provision of electrical demand (Scenario 5).

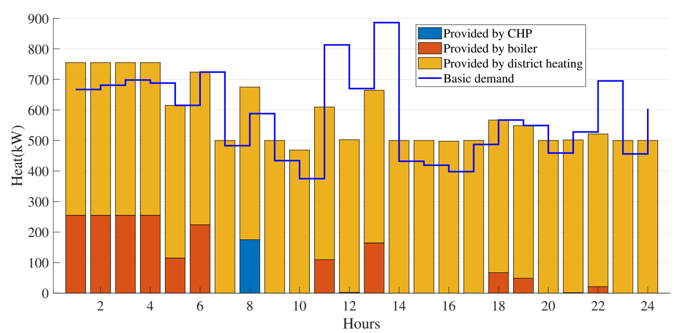

Fig. 11. Provision of thermal demand (Scenario 5).

5. CONCLUSION & FUTURE WORKS

The presence of new technology among the energy hub brings more flexibility for this energy system element as well as more complexity. The power to gas device as one of the new technologies with the feature of carbon recycling gives the capability of participation in the carbon trading market to energy hub operators. In this paper, this new flexibility was modeled among the energy hub framework to evaluate its impact on the operation cost of the system. The output results of GAMS software which is utilized for coding the optimization problem, shows that the enabling the energy hub in carbon trading market beside the demand response strategy is capable for reduction of operation cost about 2%.

In addition, below fields maybe consider as subjects of future studies:

1) strategic energy hub among carbon emission trading market: The response to this question will be interesting research subject that how will be optimization results if we assume the mentioned energy hub in this paper as the strategic market player (price maker not price taker) in the carbon trading market.

2) Comparison of different technologies of PtG: The PtG has different technologies with diverse efficiency. Comparison of these technologies impact on operation cost of energy hub is another study subject.

3) Direct hydrogen injection: The PtG is capable for direct limited injection of produced hydrogen to gas network or direct selling to the hydrogen market. Considering this facility can be another study subject which brings interesting results for the energy hub's management.

Table 3. Internal natural gas provision (kW)

t	s	Value
3	9	45.9
4	9	52.43
12	2	300
13	10	40.8
21	10	133.6
24	8	255

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