Emission based economic dispatch in the context of energy hub concept considering tidal power plants

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Energy hubs connect multi-energy carriers at the input port to various loads at the output port. The present study investigates the optimal operation of the energy hub as a centralized unit. In this paper, the main objective function is exhibited by the minimization of the total operation cost subject to a set of constraints. The cost function comprises two parts, namely the different energy carriers cost and the production cost of the environmental pollutants caused by each carrier. The constraints involved in the operation problem of the energy hub include power balance, limitations of energy storages and converters. Well-known Mixed Integer Linear Programming (MILP) is used to tackle the proposed optimization model. Tidal power plant as a new renewable energy resource is also considered in the input port of the energy hub. To investigate the effectiveness of the model, the proposed model is examined in a test system. Considering the production cost of the environmental pollutants makes the problem to be more realistic. As a result, it is recommended to consider the emission cost in the energy hub operation problem.

keywords: *Energy Hub, Emission Cost, Operation Cost, Economic Dispatch, Tidal Power Plant.*

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NOMENCLATURE

i	Index for hub's input energy carrier
j	Index for hub's output energy carrier
m	Index for converter type
n	Index for number of installed elements
t	Index for time block (each time block is equal to 1)
s	Index for energy storage
N_i	Number of hub's input energy carrier
N_o	Number of hub's output load
N_m	Number of energy converters
N_n	Number of installed elements
N_s	Number of energy storage
N_t	Number of time blocks
P_i	i^{th} input energy
L_j	j^{th} output load
P	Input matrix
L	Output matrix
C	Coupling matrix
C_o	Converter matrix
S_t	Storage matrix
η_{Trans}	Transformer efficiency
η^{e}_{CHP}	CHP electrical efficiency
η^{th}_{CHP}	CHP thermal efficiency
η_{Fr}	Furnace efficiency
η_{Exe}	Heat exchanger efficiency
η_{E}	Electrical efficiency
η_{Th}	Thermal efficiency
η_{C}	Cooling efficiency
TC	Total energy hub operation cost
π_EC	Price of energy carrier
π_Pen	Emission penalty factor
Pin_Tot	Total input of energy hub
$Pout\_Tot$	Total output of energy hub
Pin	Input energy
Pout	Output energy
Sin	Input power of storage
Sout	Output power of storage
θ^{dis}	Discharging rate of storage
θ^{ch}	Charging rate of storage

SE Stored energy in energy storage
η Component efficiency
Pin^{min} Minimum input power of energy converter
Pin^{max} Maximum input power of energy converter
Sin^{min} Minimum input power of energy storage
Sin^{max} Maximum input power of energy storage
$Sout^{min}$ Minimum output power of energy storage
$Sout^{max}$ Maximum output power of energy storage
SE^{min} Minimum stored energy in energy storage
SE^{max} Maximum stored energy in energy storage
I Installation value (binary: 1=installed, 0=else)
P_{tidal} Tidal turbine output power
V Tidal current speed
$Vcut_{in}$ Cut-in speed
V_r Rated speed
P_r Rated output power

1. INTRODUCTION

In the past years, operation and expansion planning of energy carriers such as electricity and gas were individually addressed through separate approaches. However, according to statistics, the increasingly different types of energy demand have caused energy management and planning approaches to be changed. Base on this change, loss of energy carriers and extreme production of environmental pollutants can be prevented. To achieve these goals, a highly important solution is to look at various energy carries from an integrated concept by energy hub framework in different studies. In other words, in short-term studies such as operation or demand management, as well as long-term studies such as infrastructure development plans, different types of energy carriers should be simultaneously taken into account in the integrated system named Energy Hub. From this perspective, this system should be designed and deployed with the ability to transfer, store and convert different energy resources. This study addresses the multi-energy carrier's operation at the energy hub concept [1, 2].

In the fundamental concept of the energy hub from a performance perspective, various energy carriers use different converters and storages to supply the energy demands in an integrated unit. In this concept, the connections between different infrastructures as well as the possibility for simultaneous use of carriers are provided through different short and long-term processes. So, the positive synergetic effects of carriers on each other including increased efficiency, decreased costs and increased supply reliability can be maintained [3, 4].

On the other hand, the amount of production of pollutants such as CO2, NOX, and SOX has undergone dramatic changes due to the increased energy consumption, which in turn has led to threats such as global warming and climate changes. International treaties, such as Kyoto, have been established to reduce the pollutants [5, 6]. Since different types of energy carries, which cause pollution, are involved in the concept of energy hubs, the operation's objective function should take into account the penalties for the production of pollutants in addition to decreasing the utilization costs. Furthermore, using renewable energies can be an effective solution to reduce environmental pollution and lower the operation cost of supplying a variety of energy consumers. Expansion planning, optimum operation, and appropriate design are issues that researchers encounter while thinking about the efficacy in the energy hub. Recently, several conceptual studies have been published in the field of energy hub as an integrated view of the multi-energy carrier system. The basic energy hub concept and an approach for optimization of optimal power flow focused on steady state integrated management framework [7, 8]. In addition, the impact of the interdependency of electricity and gas networks in the operation of the integrated multi-energy system is presented in [9, 10]. Optimal expansion planning of energy hub that considers the long-term mutuality of electricity and gas infrastructures is developed in [3]. Applying the energy hub context in load management for industrial customers is investigated in [11, 12]. Optimum operation of smart energy hubs that uncertainties and demand response are taken into consideration at devising a new method is deployed in [13]. Authors in [14, 15] have contributed to short-term scheduling and operation of integrated heat and power systems by deploying a robust optimization context. The hybrid stochastic-robust (HSR) method is proposed in [16] for solving the scheduling of renewable based energy hub. Residential building's energy handling considering several thermal and electrical demands is modeled in [17]. Also, the renewable energy hub model to supply different loads in the autonomous building is presented in [18]. Optimal management and operation of distributed energy resources such as wind generators in facilities under different scenarios for achieving minimum energy cost are proposed in [19, 20]. An energy program in New York as a clean energy hub is introduced in [21].

Demand side management in the building based on an energy hub framework is analyzed in [22]. Also, Recognize the required vehicles charging pattern for Plug-in hybrid vehicles is modeled in [23]. The optimal energy hub's storage size with different elements and connections is evaluated in [24]. Optimal performance analysis of solar power system considering battery and hydrogen storages is presented in [25]. Moreover, [26, 27] solved the multi-energy carrier operation, design, and planning problem considering the reliability evaluations. Recently, a comprehensive review of the different concepts and models of energy hub is presented in [28]. Also, review of the various uncertainty modeling methods on multi-energy systems optimization is done in [29]. The impact of renewable energy on different issues in the energy hub, applying the dynamic structure of the energy system, consideration of the environmental problem and energy security concerns are research gap toward energy hub.

This paper deals with the issue of optimum operation (Economic Dispatch) of energy hub as a short-term study. Satisfying the various pivotal system constraints in order to minimize the total cost (operation and emission cost) is the main objective function of energy hub Economic Dispatch (ED). The novelties of the present study could be listed as follows:

- A model is devised to carry not only energy prices but also environmental penalties in the cost function of the energy hub operation problem.
- Linear model is devised to achieve appropriate energy hub model.
- Considering tidal current turbine as one of renewable sources in input port of energy hub.

For these purposes, the energy hub ED formulation is simulated in General Algebraic Modeling System (GAMS) and the CPLEX solver is applied to find optimal global and feasible solution. The remaining section of this paper is organized as follows: the energy hub modeling, economic dispatch modeling and tidal

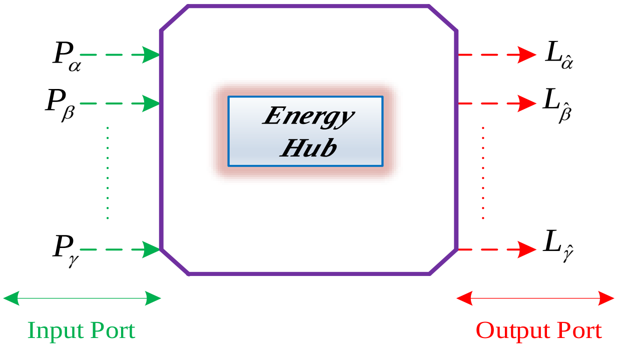


Fig. 1. Typical structure of energy hub.

power plant modeling are described methodology section. Case study, assumption and simulation results are presented in results and discussion section. Finally, the main conclusions are provided in last section.

2. METHODOLOGY

A. Energy hub modeling

In terms of performance, energy hub is simulated as Multi-Input-Multi-Output (MIMO) system. Typical structure of energy hub that contains input and output ports is shown in Fig. 1. Mathematically, the concept of energy hub is formulated in Eq. (1). The relation between j^{th} output load (L_j) and i^{th} input energy carrier (P_i) is shown by coupling matrix array (C_{ij}):

$$\begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_{N_o} \end{bmatrix}_{N_o \times 1} = \begin{bmatrix} c_{\hat{1}1} & c_{\hat{2}1} & \cdot\cdot & c_{\hat{N}_i 1} \\ c_{\hat{1}2} & c_{\hat{2}2} & \cdot\cdot & c_{\hat{N}_i 2} \\ \vdots & \vdots & \cdot\cdot & \vdots \\ c_{\hat{1}N_o} & c_{\hat{2}N_o} & \cdot\cdot & c_{\hat{N}_i N_o} \end{bmatrix}_{N_o \times N_i} \begin{bmatrix} P_{\hat{1}} \\ P_{\hat{2}} \\ \vdots \\ P_{\hat{N}_i} \end{bmatrix}_{N_i \times 1}$$

$$\Rightarrow L_{N_o \times 1} = C_{N_o \times N_i} . P_{N_i \times 1} \quad \textbf{(1)}$$

It is reasonable to say that input and output matrices are columnar and the coupling matrix is rectangular generally. It should be noted that the efficiency of components used in hub energy is less than 100% and the conditions of the operation are not perfect, calculated values in output matrix are always equal or less than the input matrix. In other words, total outputs generated by particular input should be equal or less than the considered input. Eqs. (2) and (3) show these descriptions as constraints:

$$0 \le C_{ij} \le 1 \quad \forall\, i \in \{\hat{\alpha}, \hat{\beta}, ..., \hat{\gamma}\} \;\; j \in \{\alpha, \beta, ..., \gamma\} \quad \textbf{(2)}$$

$$0 \le \sum_j C_{ij} \le 1 \quad \forall\, i \quad \textbf{(3)}$$

Moreover, Dispatch matrix is obtained by assigning energy carrier to different converters [1]. For instance, P_a (energy carrier in input port) is divided into various elements. Here, $v_{i,m}$ is shared percentage calculated by m^{th} converters and i^{th} energy carrier. According to this description, Eqs. (4)-(6) are:

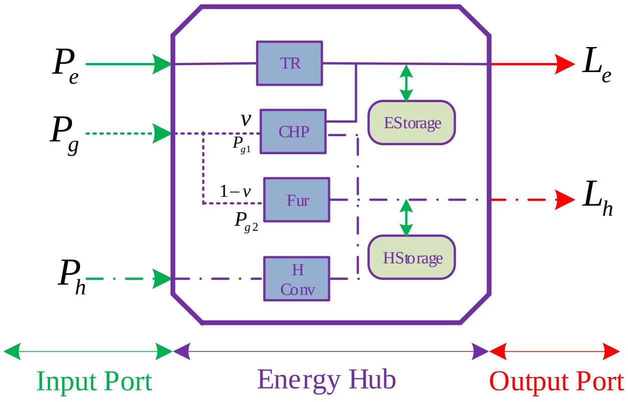


Fig. 2. Specified energy hub.

$$0 \le v_{i,m} \le 1 \quad \forall i,\ m \quad \textbf{(4)}$$

$$P_{i,m} = v_{\alpha,m} \times P_i \;\; \forall\, i, m \quad \textbf{(5)}$$

$$\sum_m v_{i,m} = 1 \quad \forall\, m \quad \textbf{(6)}$$

Efficiency matrix arrays show the relation between output and input of converters that formed by each converter's efficiency. As discussed above and based on specified energy hub shown in Fig. 2, the relationship between input and output ports can be written as Eqs. (7)-(9):

$$\begin{bmatrix} P_e \\ P_{g1} \\ P_{g2} \\ P_h \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & v & 0 \\ 0 & 1-v & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} P_e \\ P_g \\ P_h \end{bmatrix} \quad \textbf{(7)}$$

$$\begin{bmatrix} L_e \\ L_h \end{bmatrix} = \begin{bmatrix} \eta_{Trans} & \eta^{e}_{CHP} & 0 & 0 \\ 0 & \eta^{th}_{CHP} & \eta_{Fr} & \eta_{Exe} \end{bmatrix} \begin{bmatrix} P_e \\ P_{g1} \\ P_{g2} \\ P_h \end{bmatrix} \quad \textbf{(8)}$$

$$\begin{bmatrix} L_e \\ L_h \end{bmatrix} = \begin{bmatrix} \eta_{Trans} & v \times \eta^{e}_{CHP} & 0 \\ 0 & v \times \eta^{th}_{CHP} + (1-v) \times \eta_{Fr} & \eta_{Exe} \end{bmatrix} \begin{bmatrix} P_e \\ P_g \\ P_h \end{bmatrix} \quad \textbf{(9)}$$

It is necessary to mention that within input and output ports, different kinds of storage can be installed. Consequently, some of the production or consumption of the energy hub in input and output ports are supplied through them. Commonly, storage elements are modeled at the energy hub's output port. Based on the aforementioned note, Eq. (9) can be modified as follows:

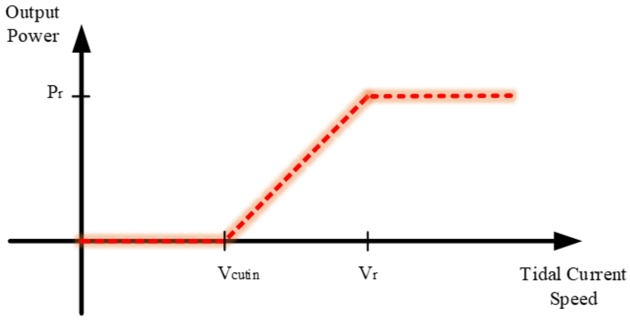


Fig. 3. Conceptual model of tidal power plant.

$$\begin{bmatrix} L_e \\ L_h \end{bmatrix} = Co + St$$

$$Co = \begin{bmatrix} \eta_{Trans} & v \times \eta^{e}_{CHP} & 0 \\ 0 & v \times \eta^{th}_{CHP} + (1-v) \times \eta_{Fr} & \eta_{Exe} \end{bmatrix} \begin{bmatrix} P_e \\ P_g \\ P_h \end{bmatrix}$$

$$St = \begin{bmatrix} Sout_e - Sin_e \\ Sout_h - Sin_h \end{bmatrix} \tag{10}$$

B. Tidal power plant

Several countries have recently faced with such issues as the emission of environmental pollutants, abnormal climatic changes, and the shortage of fossil fuel resources. Renewable energies can be used as a solution to these problems. There are various sources of renewable energy, such as solar energy, wind energy, geothermal energy, biomass energy, ocean energy, and geothermal energy. Each of these sources has unique properties. A tidal current turbine that converts the potential energy from the ocean into electricity is one of the ocean resources. Usually, the tidal plants are located in a sultry region with special weather conditions. Common technologies in tidal power stations are relatively evolved, due to their similarities with technologies used in hydroelectric power plants and wind farms. In general, there are two different methods to generate electricity from the ocean. The first one requires a dam and water storage system, In contrast to this method, another process uses tidal flows. This study aimed to investigate the second type of tidal power stations [30].

Due to environmental concerns, tidal power plants, which do not need high tidal range and dam construction, have recently drawn more attention in researches. It should be noted that studies on tidal power plants have shown that they are highly reliable with very low maintenance costs.

The conceptual model of tidal power plants is very comparable to the wind farm model shown in Fig. 3. Like a wind farm model, it includes cut-in and rated velocity characteristics. However, there is no need for cut-out velocity because flows consider limited variations and negligible instability which don't damage tidal turbines. Indeed, the tidal power output depends on tidal current speed and design specifications. In previous researches [31, 32], three criterions as a linear function are determined for the expression this dependency:

$$P_{tidal} = \begin{cases} 0 & V < Vcut_{in} \\ P_r \frac{V - Vcut_{in}}{V_r - Vcut_{in}} & Vcut_{in} \le V < V_r \\ P_r & V_r \le V \end{cases} \tag{11}$$

C. Economic dispatch for energy hub

The objective function of short-term operation problem (Economic Dispatch) of an energy hub is to minimize total operation cost of serving different loads subject to related constraints. Here, the emission penalties are taken into account as second part of total cost. Mathematically, formulations are as follows:

$$Min(TC) = Minimizing \left\{ \sum_{i=1}^{N_i} \sum_{t=1}^{N_t} \left(\begin{array}{l} [\pi\_EC_{i,t} \times Pin\_Tot_{i,t}] + \\ [\pi\_Pen_{i,t} \times Pin\_Tot_{i,t}] \end{array} \right) \right\} \tag{12}$$

The prevailing constraints in this optimization are listed as follows:

- Input energy balance:

$$Pin\_Tot_{i,t} = \sum_{m=1}^{N_m} \sum_{n=1}^{N_n} Pin_{i,m,n,t} \tag{13}$$

- Output load balance:

$$Pout\_Tot_{j,t} = \left\{ \begin{array}{l} \left(\sum_{m=1}^{N_m} \sum_{n=1}^{N_n} Pout_{j,m,n,t} \right) + \\ \left(\sum_{s=1}^{N_s} \sum_{n=1}^{N_n} \left(Sout_{j,s,n,t} - Sin_{j,s,n,t} \right) \right) \end{array} \right\} \tag{14}$$

- Charge and discharge of storages

$$SE_{s,n,t} = SE_{s,n,t-1} - \left(Sout_{s,n,t} \big/ \theta_s^{dis} \right) + \left(Sin_{s,n,t} \times \theta_s^{ch} \right) \tag{15}$$

- Input/output energy of converters:

$$Pout_{j,m,n,t} = \sum_{i=1}^{N_i} \left(\eta_{i,j,m} \times Pin_{i,m,n,t} \right) \tag{16}$$

- Converters limits:

$$I_{i,m,n} \times Pin_{i,m}^{min} \le Pin_{i,m,n,t} \le I_{i,m,n} \times Pin_{i,m}^{max} \tag{17}$$

- Storages limits:

$$\begin{array}{l} I_{s,n} \times Sin_{s,n,t}^{min} \le Sin_{s,n,t} \le I_{s,n} \times Sin_{s,n,t}^{max} \\ I_{s,n} \times Sout_{s,n,t}^{min} \le Sout_{s,n,t} \le I_{s,n} \times Sout_{s,n,t}^{max} \\ I_{s,n} \times SE_s^{min} \le SE_{s,n,t} \le I_{s,n} \times SE_s^{max} \end{array} \tag{18}$$

It should be noted that, as mentioned in energy hub equations, the multiplication of the variables $Pin_{i,t}$ and $v_{i,m,t}$ is a factor that will make the problem nonlinear. Here, the new $Pin_{i,m,n,t}$ variable was used to eliminate the nonlinearity factor. It is worthy to mention that the suggested model is not a typical one, and can be used for any practical energy system. For instance, the indices *i* and *j* can signify any kinds of input and output.

Converter and capacity of the storage limits, Charge and discharge of storage, input/output energy of converters are given in Eqs. (15)-(18). Base on the main objective function, the storages are normally discharged/charged when the energy carrier's price is high/low, respectively. Consider a state in that the carrier's price is set to high level and the discharge percentage is not appropriate to supply the loads. In this situation, the outputs of the other elements (converters) play a dynamic role to provide the energy hub loads (no matter the price of energy). It is worthy to mention that, charging (θ^{ch}) and discharging (θ^{dis}) rate of storages are denoted by η_E, η_{Th}, and η_c in Table 1.

3. RESULTS AND DISCUSSION

A. Case study and assumptions

In this paper, the case study is common sample energy located in the sultry climate of Iran. In which input port contains electricity and gas as supplier resources and several loads (electrical, cooling and thermal) are supplied from the output port. The structure of the aforementioned energy hub as a case study is shown in Fig. 4. Also, based on Iran Grid Management Company's data, the energy carrier's prices are shown in Fig. 5 [33]. The tidal turbine is also included in input port and current tidal speed is assumed as depicted in Fig. 6. (Practicable output power of this assumed tidal generator is 5kW that Cut-in speed=0.7 m/sec and rated-speed=2.25 m/sec) [34]. According to Iran electricity market regulations and Renewable Energy and Energy Efficiency Organization's laws [33, 35], tidal generation cost is paid by upstream network owner and gas price contains three tariffs. Furthermore, the expected values of several loads are shown in Fig. 7. It should be noted that energy prices, cost, and energy (power) are assumed per unit (p.u.) and base quantities are equal to 0.015 $/1kw, 0.015$ and 1kw respectively.

As mentioned earlier, it is assumed that the test system is located in a sultry climate, where the installation of tidal power plants is possible. In addition to electrical and thermal loads, considering the climatic conditions of sultry regions, the cooling load should be supplied through the energy hub.

Technical specifications of mentioned energy hub components are presented in Table 1 (electrical converter (EConv), transformer (TR), combined cooling, heating and power (CCHP), furnace (Fur), electrical storage (EStorage), heat storage (HStorage) and cool storage (CStorage)). Also, the maximum of η index is assumed to seven. Furthermore, Emission penalty factors used in total cost are 1.1(p.u) and 0.6 (p.u) for electrical and gas respectively.

In order to investigate the effect of energy storages, energy hub concept and tidal power plant at total operation cost, several states are applied to analyze the different aspects. The different characteristic of these states are:

- State1 (St1): Energy Hub Concept ×, Storage Elements ×, Tidal Plant ×
- State2 (St2): Energy Hub Concept ✓, Storage Elements ×, Tidal Plant ×
- State3 (St3): Energy Hub Concept ✓, Storage Elements ✓, Tidal Plant ×
- State4 (St4): Energy Hub Concept ✓, Storage Elements ✓, Tidal Plant ✓

Finally, the aforementioned optimization is modeled in GAMS software and CPLEX solver is applied to solve it. Its main limitations and assumptions are as follows: 1) feasibility and optimality tolerance are equal to 10-6, 2) iteration limit is 2 × 109, 3) limit on singularity repairs is 10, 4) running time limit is 1000 sec., and 5) markowitz pivot tolerance is equal to 0.01 [36, 37]. The simulation is implemented on a PC with 5GHz CPU and 8GB RAM.

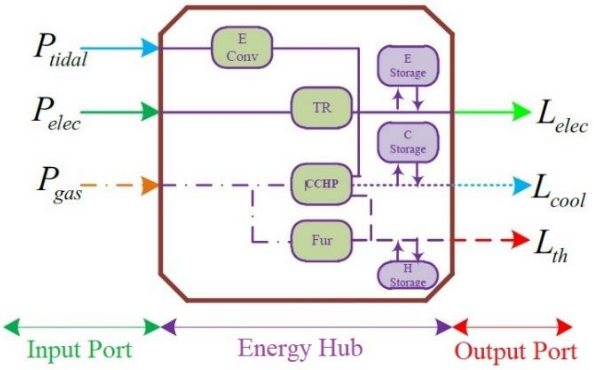


Fig. 4. Structure of energy hub as case study.

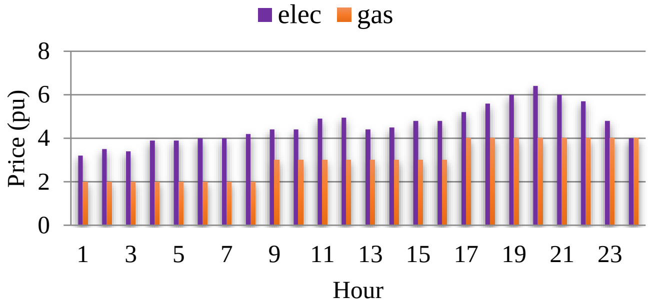


Fig. 5. Electricity and gas price for 24 hours.

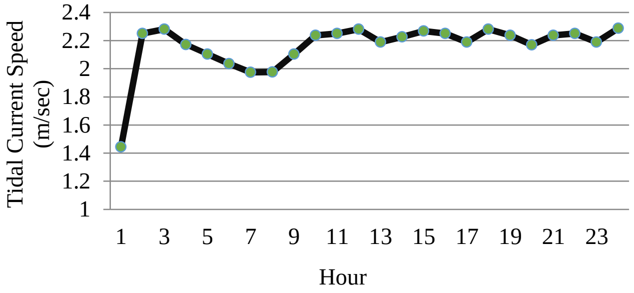


Fig. 6. Current tidal speed for 24 hours.

B. Results

The main simulation results including the amount of total cost (operation and emission) and different energy hub inputs are brought in Figs. 8-10 respectively. The operation cost of the energy hub at a 24-hour horizon and the environmental pollution cost in different assumed states are depicted in Fig. 8. As seen in the results, the operation cost in state1 is greater than others. Due to the following assumptions, the mentioned mode possesses the highest operating cost: a) The input of gas through CCHP cannot supply the electricity load, b) Energy storage systems have not been included into the model, and c) Tidal power sources have not been taken into account.

Indeed, the mentioned state is the most uneconomical one.

Table 1. Technical specifications of energy hub components

Hub Element	Max input power	Min input power	η_E	η_{Th}	η_c	Max energy	Min energy
EConv	5	0	0.98	-	-	-	-
TR	12	0.12	0.97	-	-	-	-
CCHP	10	0.1	0.4	0.45	0.43	-	-
Fur	10	0.1	-	0.75	-	-	-
EStorage	5	0	0.95	-	-	11	0.5
HStorage	3	0	-	0.9	-	12	0.6
CStorage	3	0	-	-	0.9	10	0.5

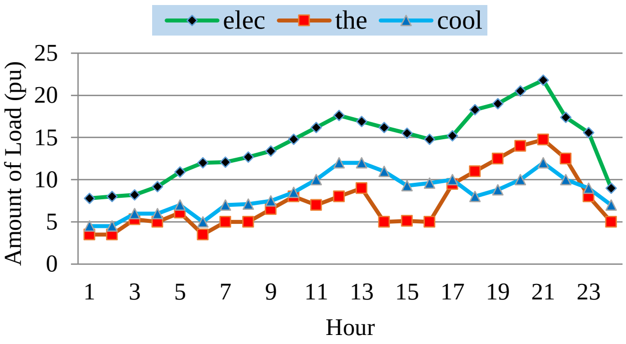
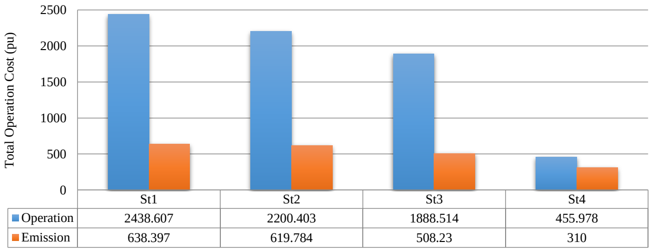
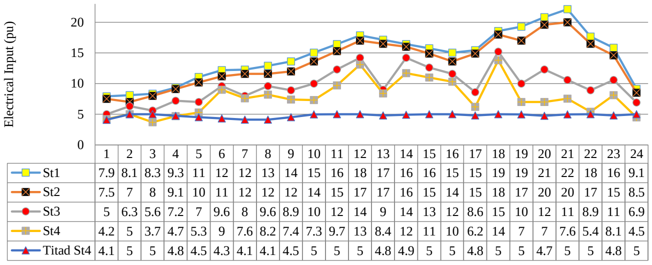


Fig. 7. Electrical, thermal and cooling loads.



	St1	St2	St3	St4
Operation	2438.607	2200.403	1888.514	455.978
Emission	638.397	619.784	508.23	310

Fig. 8. Total (operation and emission) cost of energy hub in each state.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
St1	7.9	8.1	8.3	9.3	11	12	12	13	14	15	16	18	17	16	16	15	15	19	19	21	22	18	16	9.1
St2	7.5	7	8	9.1	10	11	12	12	12	14	15	17	17	16	15	14	15	18	17	20	20	17	15	8.5
St3	5	6.3	5.6	7.2	7	9.6	8	9.6	8.9	10	12	14	9	14	13	12	8.6	15	10	12	11	8.9	11	6.9
St4	4.2	5	3.7	4.7	5.3	9	7.6	8.2	7.4	7.3	9.7	13	8.4	12	11	10	6.2	14	7	7	7.6	5.4	8.1	4.5
Titad St4	4.1	5	5	4.8	4.5	4.3	4.1	4.1	4.5	5	5	5	4.8	4.9	5	5	4.8	5	5	4.7	5	5	4.8	5

Fig. 9. Electrical and tidal inputs of energy hub.

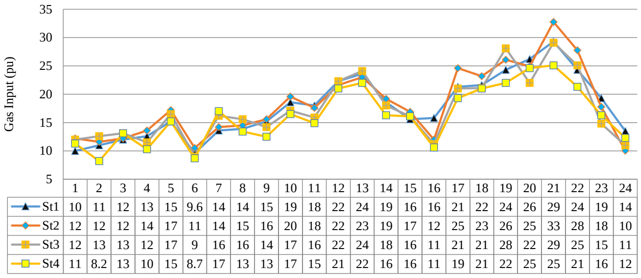
On the other hand, it should be noted that in this state, environmental pollution costs are higher than the rest. Therefore, from an environmental point of view, this state is in the worst one too. Overall, this mode can be described as the worst condition for operating the energy hub. The rest of the states and their effects on costs are examined below.

Taking into account the concept of the energy hub, and the principle that the electrical load can be supplied through CCHP, and that the energy can be exchanged through various carriers, the operation costs are lower compared to the previous mode. It is reasonable to say that the environmental costs have also been reduced in state2 compared to the first state. However, it should be noted that since storage units are neglected here, in economic and technical terms, it is still not a suitable mode for designing and operating of energy hub.

As it can be seen, the operating cost in the third state is lower than the first and second state, and the environmental costs are lower. In this mode, various kinds of storage units are accounted for in the energy hub. In this process, once the storage units are charged, they can provide the related loads at different hours. Providing a portion of the electrical, cooling, and heating loads through the respective storage units can reduce the system's need for input carriers, which will ultimately lower the costs. Moreover, as it can be seen, the environmental pollution costs have been reduced in proportion to the decrease in energy received through the input port. In fact, when the system in question lacks sources of renewable energy, such as tidal power, the best choice for the operator of the energy hub is the third state. Here, the concepts of converting energy carriers to each other and also the use of various types of storage units have been employed to supply the desired loads. Now, after adding a tidal plant in the next state, the results will be examined. In the last state, in addition to the conditions governing the previous state, a tidal plant is added to the input port. The electrical power generated by tidal and upstream power received is shown in Fig. 9. To improve the conditions of the energy hub using this kind of source, first, the power generated by the tidal plant should be injected into the grid through a converter. The results show that there has been a substantial decrease in the costs of this state compared to others. This decrease is due to the supply of a significant portion of the electrical load by the tidal plant, which has led to a significant reduction in the use of gas and electricity carriers in the input port. On the other hand, there has been a remarkable reduction in environmental pollution costs. Generally, in short and long-term studies, the use of renewable energies in different systems will lead to sustainable development.

4. CONCLUSIONS

Optimum operation (Economic Dispatch) problem in energy hub concept based on Mixed Integer Linear Programming (MILP) is implemented in this study. In order to have a realistic energy hub, different loads in output port such as electrical, thermal and cooling are also considered. Moreover, several input sources like electrical, gas and tidal power plant (as one of renewable energy) are used in input port. Investigating the effectiveness of the proposed model, different states are studied. As is shown in different cases, the most realistic one, namely state4, simu-



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
St1	10	11	12	13	15	9.6	14	14	15	19	18	22	24	19	16	16	21	22	24	26	29	24	19	14
St2	12	12	12	14	17	11	14	15	16	20	18	22	23	19	17	12	25	23	26	25	33	28	18	10
St3	12	13	13	12	17	9	16	16	14	17	16	22	24	18	16	11	21	21	28	22	29	25	15	11
St4	11	8.2	13	10	15	8.7	17	13	13	17	15	21	22	16	16	11	19	21	22	25	25	21	16	12

Fig. 10. Gas input of energy hub.

lated the different aspects of multi-carrier energy hub system. In addition to the technical limitations of the components, input/output balance constraints play a vital role in the solution process. This is while, supplying various loads by different elements and using energy delivered through the upstream grid is a major challenge in energy hub operation. It is argued that, total cost reduction is occurred by considering energy hub concept, energy storage elements and tidal power plant.

Directions for our future work consist of investigating the resiliency assessment, security energy evaluation and deploying ancillary service in the energy hub operation problem.

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