Original Research Article

Energy Management Optimizing in Energy Hub with Regard to Pollution and Storage Effects

ABSTRACT

Aims: The purpose's paper reduces total cost of system, generation cost and pollution cost simultaneously in a proposed model of HUB.

Study design: Case study of model includes one energy hub with different characteristics in twenty-four hours. The cost function of this model is composed of two parts. The part one is related to generation cost and the part two is cost function related to emission penalties.

Place and Duration of Study: IAU, Iran, November 2014 - February 2016.

Methodology: Model's scenario obtained through DICOPT solver of GAMS software version 24.1.

Results: With using paper's simulation result obtained selecting the best optimal device that it reduced generation cost, pollution cost and total cost.

Conclusion: Integrated energy systems (HUB) is a multi-generation system where multiple energy carriers input to the hub are converted, stored and distributed in order to satisfy electrical and heat energy demands. As well as, the paper will be able to get limit of equipment to unpredictable extra cost not logged to system (discuss affect cost of system). This paper is developed a hybrid approach for integrated energy system, ambient temperature and pollution effects. Therefore, pollution have saw as output cost energy hub. In fact, pollution considered as negative yields. Also, the paper presented optimal scheduling by use charging and discharging equations mechanism (effect of storage) reduced by both pollution, generation and total cost simultaneously as objective function in 24 hours.

Keywords: (Energy storage, multi carrier energy systems (Hub), optimizing energy, pollution effects)

1. INTRODUCTION

Climate changes and energy security are among the central parameters will shape the energy systems world-wide. The built environment stands for close to half of all energy use and emissions. Therefore, this sector will be central importance for finding solutions to the grand challenges ahead (Mancarella, 2014; Shabanpour-Haghighi et al, 2015). With the industry development and increasing consumption of energy resources, management of energy is now an important issue in different industries. Moreover, taking into account the serious environmental pollutions made by the manufacturing industries, minimizing these emissions have become very important. Since energy carriers as raw materials energy producers have a significant role in the cost of energy generation. Increasing need for energy carriers the loss of global energy resources causes to always works is presented in the ways to reduce and optimize energy consumption and cost in the industry.

With increasing energy carriers prices and restrictions fossil resources, special attention to the energies that have been transferred capability and greater consistency with the environment as well as lower cost with higher energy efficiency. Accordingly, many studies have been done. In (Mancarella, 2014) the aim of paper is thus to provide the reader with a comprehensive and critical overview of the latest models and assessment techniques that are currently available to analyze multi carrier energy system (MES) and in particular distributed multi generation (DMG) systems, including for instance concepts such as integrated energy systems (energy hubs), micro grids (MGs) and virtual power plants (VPPs) as well as various approaches, criteria for energy, environmental and techno-economic assessment.

In (Parisio and et al, 2012) a control approach using robust optimization (RO) techniques are proposed for a robust optimization problem of energy hub operations. Simulation results underline the benefits resulting from the application of the proposed approach to an energy hub structure designed in Waterloo, Canada. In (Moeini-Aghtaie and et al, 2013) a concept of future energy networks provides in particular energy hub that enable to the design new approach of multiple energy carriers systems, modeling and analysis of appropriate equipment structures for proper planning and operation of multiple energy carriers systems and flexible combination of different energy carriers. In (Maroufmashata and et al, 2015) the presented energy hub model represents a general and comprehensive approach of modeling conversion and storage of multiple energy carriers. The paper presented a framework for combined steady-state modeling and optimization of multi-carrier energy systems. The models are based on the novel concept of energy hubs; the multi-carrier system is considered as one integrated system of interconnected energy hubs. Using with the model is defined various integrated optimization problems that provides optimal power flow and dispatch approaches are able to estimate the optimal coupling between energy infrastructure. In (Geidl, 2007) presented an approach for the combined optimization of coupled power flows of different energy carriers. This paper's model is based on distributed energy resources (DERs). The features of the developed technique are demonstrated in a numerical example.

This paper provided an approach for combining the integrated energy systems (Hub), the environmental pollution and also the effect of ambient temperature, the paper optimized the amount of energy carriers consumed. Moreover, pollutions are minimized according to different strategies of industries. On the other hand, using this procedure is obtained the working point approximation of each equipment. One of another feature paper storage systems were seen in the hub output. As well as, in this research to assessment generation cost, emission cost and total cost of the objective function during a 24 hour period.

The paper is organized as follows. The energy hub concept and a brief overview of energy hub are presented in section 2. Detail formulation of the main idea behind the paper and pollution and cost parameters are defined in section 3. Results are debated in detail and effect of storage on cost and emission of energy hub are defined in section 4. Finally, conclusions are drawn in Section 5.

2. ENERGY HUB CONCEPT

This section described energy hub concept. Electric energy (taken from electrical grid) is the carrier of fuel and gas energy in the system input. In the output, electric and thermal energies are required to respond to the electric and thermal demand. Inside the transducer, the electric energy is generated by transformer and combined heat and power (CHP) output. An amount of electric energy is stored in the transducer by electric storage. The gas energy carrier is used as CHP fuel which may produce heat as well as electricity. Fuel carrier may be used to convert fuel to thermal energy. On the output, a thermal storage is mounted. The energy hub is shown in the Fig. 1.

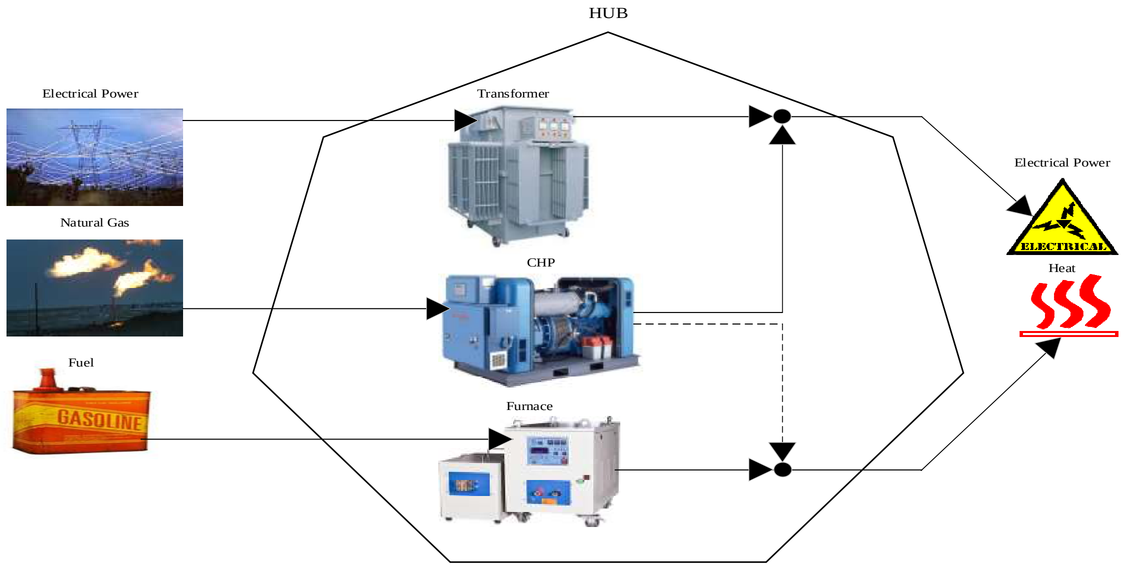

Fig. 1. An integrated energy system (Hub)

3. MATHEMATICAL MODELING

An energy hub is described in Fig. 1 by the following equations. For the system shown in Fig. 1, objective function and constraints equations are used equations 1 - 20 as titles in 3.1 to 3.8.

3.1 Process lack of Storage Unit (Maroufmashata and et al, 2015)

The following equations 1 - 12 described about effect of storage unit.

$$L_e = \eta_T P_e + v\eta_{Te} P_g \quad (1)$$

$$L_h = v\eta_{GT_h} P_g + (1-\text{v})\eta_{F_e} P_g + \eta_{HE} P_h \quad (2)$$

In equations (1-2), P_e, P_g and P_h are stand for electric carriers, gas carriers and heat carriers, respectively. Also, the transformer efficiency, electrical efficiency, heat efficiency, heat furnace efficiency are denoted with η_T, η_{Te}, η_{HE}, η_{F_e} respectively. η_{GT_h} is gas turbine CHP of gas-heat efficiency. As well as, electrical load and heat load are denoted with L_e and L_h respectively. Also, v is dispatch factor.
The equations (1) and (2) may be written as matrices:

$$\begin{bmatrix} L_e \\ L_h \end{bmatrix} = \begin{bmatrix} \eta_T & v\eta_{Te} & 0 \\ 0 & v\eta_{GT_h} + (1-\text{v}\eta_{F_e}) & \eta_{HE} \end{bmatrix} \begin{bmatrix} P_e \\ P_g \\ P_h \end{bmatrix} \quad (3)$$

Totally, equation (3) may be written as:

$$\text{L} = \text{CP} \quad (4)$$

Where C is called the converter coupling matrix and system input, system output are denoted with L and P respectively.

3.2 Inclusion of storage (Geidl, 2007)

The storage consists of 2 parts: Electric storage and a thermal one (isolated water reservoir). Adding storage, equation (4) may become as follows:

$$L(\mathrm{t}) = CP(t) - S(\mathrm{t})\dot{E}(\mathrm{t}) \quad (5)$$

$$\begin{bmatrix} L_e(t) \\ L_h(t) \end{bmatrix} = \begin{bmatrix} Ne & Nchpe & 0 \\ 0 & Nchpg & Nh \end{bmatrix} \begin{bmatrix} P_e(\mathrm{t}) \\ P_g(t) \\ P_h(t) \end{bmatrix} - \begin{bmatrix} S_e(\mathrm{t}) & 0 \\ 0 & S_h(t) \end{bmatrix} \begin{bmatrix} \dot{E}_e(t) \\ \dot{E}_h(t) \end{bmatrix} \quad (6)$$

In which Ne is transformer conversion coefficient, $Nchpe$ is the efficiency of electricity generation by CHP, $Nchpg$ is the percentage efficiency if heat generation by CHP and Nh is the heat generation efficiency. Storage electrical energy derivative and storage heat energy derivative are shown by $\dot{E}_e(\mathrm{t})$ and $\dot{E}_h(\mathrm{t})$ respectively.

A third matrix (C) describes the relation of operation on input carriers for the output generate.

According to the resources in (Geidl, 2007), the values of matrices ε and S are defined as follows. It should be noted (Geidl, 2007) takes into account a heat storage on the input and a battery on the output, so author may find the matrices by the same approach.

$$\begin{bmatrix} S_e(t) & 0 \\ 0 & S_h(t) \end{bmatrix} \begin{bmatrix} \dot{E}_e(t) \\ \dot{E}_h(t) \end{bmatrix} = \begin{bmatrix} \dfrac{1}{E_e(t)} & 0 \\ \dfrac{1}{E_e(t)} & 0 \end{bmatrix} \begin{bmatrix} E_t - E_{t-1} + E_{stb} \\ h_t - h_{t-1} + h_{stb} \end{bmatrix} \quad (7)$$

In fact, E described the stored amount of energy in t_{th} battery. $E_h(t)$ and $E_e(t)$ are the amounts of delivered energy time t by battery charging and discharging.

Values of E_h and E_e are obtained in the process of optimization by a creative procedure.

$$E_e(t) = I_c(t)e^{+}_{e\_charge} + (1 - \mathrm{I}_c(\mathrm{t})) / \mathrm{e}^{-}_{e\_discharge} \quad (8)$$

$$E_h(t) = I_d(t)e^{+}_{h\_charge} + (1 - \mathrm{I}_d(\mathrm{t})) / \mathrm{e}^{-}_{h\_discharge} \quad (9)$$

The values $e^{+}_{e\_charge}$ and $\mathrm{e}^{-}_{e\_discharge}$ are electrical storage charging and discharging capacities. Also, $e^{+}_{h\_charge}$ and $\mathrm{e}^{-}_{h\_discharge}$ described the charging and discharging capacities of heat sink for energy exchange, respectively.

Also, constraints of bounds are defined as:

$$0 \le P_i \le P_{i\_\max} \qquad i \in e, g, gasoline \quad (10)$$

$$L_e = \eta_{chp_e} P_e + \eta_{gasoline} P_g - \left(\frac{E_t - E_{t-1} + E_{stb}}{E_e(t)}\right) \quad (11)$$

$$L_h = \eta_{chp_h} P_g + \eta_{gasoline} P_h - \left(\frac{h_t - h_{t-1} + h_{stb}}{E_h(t)}\right) \quad (12)$$

Where e, g and $gasoline$ are electrical, gas and gasoline carriers, respectively.

3.3 Storage Systems Constraints

Constraints of storage electrical and heat systems are shown in following equations:

$$\mathrm{M}_e = \frac{E_t - E_{t-1} + E_{stb}}{E_e(t)} \quad (13)$$

$$\mathrm{M}_h = \frac{h_t - h_{t-1} + h_{stb}}{E_h(t)} \quad (14)$$

$$-\mathrm{M}_{i\_\max} \le M_i \le M_{i\_\max} \qquad i \in e,h \quad (15)$$

3.4 Generation Cost

Fixed generation cost is shown by a. Also, b and c are variable cost and operation cost of CHP. Also, $M_{\max}$ shows total maximum stored power and "Electrical cost" is the price of energy carrier purchased from the grid per unit (p.u.). "Fuel cost" is the price of fuel carrier in p.u. of fuel used in the furnace.

$$Generation\quad Cost = \sum_{t=1}^{24} \left\{ \begin{array}{l} (\mathrm{a} + \mathrm{b}\mathrm{P}_g(\mathrm{t}) + \mathrm{c}\mathrm{P}_g^2(\mathrm{t})) \\ + P_e(\mathrm{t})\,\mathrm{Electrical\quad Cost(t)} + \\ \mathrm{P}_{gasoline}(\mathrm{t})\,\mathrm{Fuel\quad Csot} \end{array} \right\} (16)$$

3.5 Inclusion Impact of Pollution Penalty

Emission cost is shown in equation (17):

$$Emission\quad Cost = \alpha + \beta P_g + \gamma P_g^2 \quad (17)$$

Coefficients α, β and γ are the coefficients of pollution cost which are determined by air quality control authorities.

A great amount of the pollution made by energy hub is by particulates and toxic emissions. An objective function is first introduced in this section of the paper, which is as follows:

Providing thermal and electric energy is variously important in different industries. In some industries, the pollution regulations are not strict because of special conditions and the importance of demand. In others, due to concerns of pollution and the importance of green energies, they are obeyed profoundly. The factor W is defined to simulate the demand.

3.6 Pollution Cost

Pollution is often produced by toxic emissions from CHP or by thermal furnace. In some plants with gas power station, the pollution is from chimneys. The pollution cost function is defined as equation (18):

$$Total\quad Emission\quad Cost = \sum_{t=1}^{24} \left\{ \begin{array}{l} \alpha + \beta \mathrm{P}_g(\mathrm{t}) + \gamma \mathrm{P}_g^2(\mathrm{t}) \\ + \alpha + \beta P_{gasoline}(\mathrm{t}) + \gamma P_{gasoline}^2(\mathrm{t}) \end{array} \right\} \quad (18)$$

3.7 Exert Influence of coefficient W

Weighting factor W determines the significance of the pollution to clean energy ratio. In fact, W is used to determine the operational constraints of each industrial unit which defines its strategies based on this factor. It's shown as equation (19):

$$Total\quad Cost = W \times Generation\quad Cost + (1-W) \times Emission\quad Cost \quad (19)$$

3.8 Inclusion of Ambient Temperature Effects on CHP Performance

In order to determine the effects of temperature on CHP performance, the data concerning CHP performance are obtained in different temperatures for every particular model of CHP. Afterwards, the temperature variation data on different days of each season are obtained statistically from the meteorological and related organizations. Therefore, adapting the two diagrams, the paper may find the CHP efficiency on different hours of each day with a certain approximation, or the paper may attach a thermometer to the system which can read the temperature data on every hour and enter the efficiency value obtained into the system. Equation of CHP effects are as follows in (20):

$$CHP\ \ \text{Effect}\ \ Generation\ \ Cost = \sum_{t=1}^{24} \left\{ \begin{array}{l} (\text{RAND} \times (\text{a} + \text{bP}_g(\text{t}) + \text{cP}_g^2(\text{t})) \\ + P_e(\text{t})\,\text{Electrical Cost (t)} \\ + \text{P}_{gasoline}(\text{t})\,\text{Fuel Cost} \end{array} \right\} \quad (20)$$

In equation (20), the factor RAND is the impact factor of CHP.

Thus, overall objective function of the system is minimizing the total cost by minimizing pollution and energy generation costs. Totally, Equation of objective function's paper is expressed as follows:

$$Objective\ Function = Min\,(Totall\ Cost) \qquad (21)$$

4. SIMULATION RESULT

For solve paper's modeling problem, authors are used from DICOPT solver of GAMS software version 24.1. DICOPT is a program for solving mixed-integer nonlinear programming (MINLP) problems that involve linear binary or integer variables and linear and nonlinear continuous variables. In Fig. 2 simulation results are divided to 4 steps. Steps includes step 1: Inclusion cost in the model without storage unit. Step 2: Inclusion emission in the model without storage unit. Step 3: Inclusion cost and saver in the model with storage unit. Step 4: Inclusion emission and saver in the model with storage unit (blue, orange, gray, and yellow curve shown in Fig. 2, respectively).

At first step, according to paper modeling equation (16) which in the past noted, model cost regardless of the storage unit has been considered in the proposed model (Fig. 1). Simulation output in accordance with blue curve is visible in Fig. 2. At second step, according to paper modeling equation (17) which noted in the past. Greenhouse emission, regardless of the storage unit has been considered in the proposed model (Fig. 1). Simulation output in accordance with orange curve is visible in Fig. 2. In the third step, according to paper modeling equations (1-4) mentioned in the past, the impact of storage costs and simultaneously on the model taking into account the storage unit has been considered in model (model is more complex than the proposed model). Simulation output in accordance with gray curve is visible in Fig. 2. In the fourth step, according to paper modeling equations (5- 12) mentioned in the past, the impact of costs and greenhouse emission simultaneously in the model taking into account the storage unit is included in model (model is more complex than the model proposed). Simulation output in accordance with yellow curve is visible in Fig. 2.

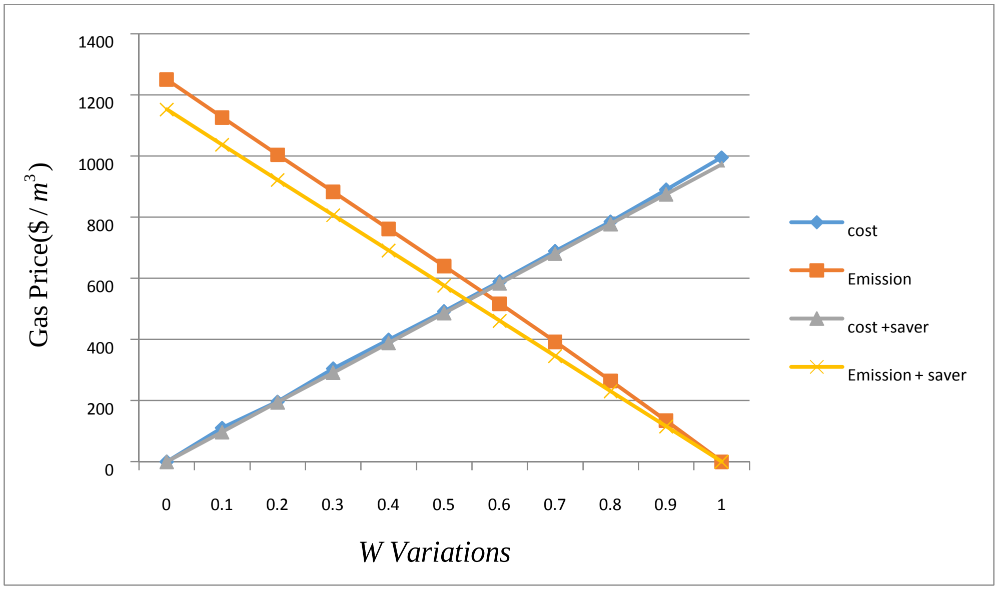

Fig. 2. Investigating the storage effect.

Table 1 shows the weighting factor changes in the objective function (equation (21)) with respect lack of storage units in the proposed model and its impact on generation costs, greenhouse gas emissions and total cost.

Table 1. Investigation the storage effects

W	With Storage Unit			Without Storage Unit		
	Cost ($/h)	Emission (g/kwh)	Total Cost ($/h)	Cost + Saving	Emission + Saving	Total Cost + Saving
0	0	1249.984	1249.984	0	1152	1152
0.1	110.659	1126.085	1236.744	97.2	1036.8	1149.12
0.2	196.485	1003.868	1200.326	194.4	921.6	1146.12
0.3	305.222	882.5707	1187.793	291.6	806.4	1143.36
0.4	399.159	761.4572	1160.616	388.8	691.2	1140.48
0.5	492.157	639.8113	1131.968	492.157	576	1137.6
0.6	589.664	516.9385	1106.603	589.664	460.8	1134.72
0.7	689.357	392.1651	1081.522	689.357	345.6	1131.84
0.8	785.517	264.8372	1050.354	785.517	230.4	1128.96
0.9	890.166	134.3206	1024.468	890.166	115.2	1126.08
1	995.144	0	995.144	995.144	0	1123.2

Results of Table 1 shows the improved numerical values of a storage unit generation, greenhouse gas emissions and total costs in the proposed model. In Table 1, there is almost no difference for gas prices between cost and cost + saver mode, and also between emission and emission + saver mode in amounts of W because of this difference will see with presence of multi-saver in model.

4.1 Inclusion of gas price variations in costs (W=0.6)

This section includes 3 steps. Steps includes step 1, 2 and 3. Step 1: Inclusion cost in the model and impact of adding the gas price is estimated on other costs (blue curve is shown in Fig. 3). Step 2: Inclusion emission in the model and impact of adding the gas price is estimated on other costs (orange curve is shown in Fig. 3). Step 3: Inclusion total cost in the model and impact of adding the gas price is estimated on other costs (gray curve is shown in Fig. 3). According to the Fig. 3, gas price increase may heighten other costs. However from there on, no increment occurs on the diagrams with gas price variations because whatever the price is increased. There is still an amount of thermal load which may need minimum amount of gas carrier to respond and even if the overall capacity of alternative carriers are used up, they may not be able to respond to the demand.

Gas price on the pollution cost section is first decreasing; however, from a certain point on the variations are constant and the diagram has a very soft slope. The reason is that, first with a gas carrier price increase, the system decreases the amount of its consumption automatically. So, that the pollutions of heat and electricity power station are lowered. However, the pollution never be reaching zero because the fuel power station is still active and there is still some thermal demand. So, with respect to price increase, system still needs gas carriers to provide heat (thermal) demand.

Table 2 shows the effect of changes in the cost of gas carrier on the cost.

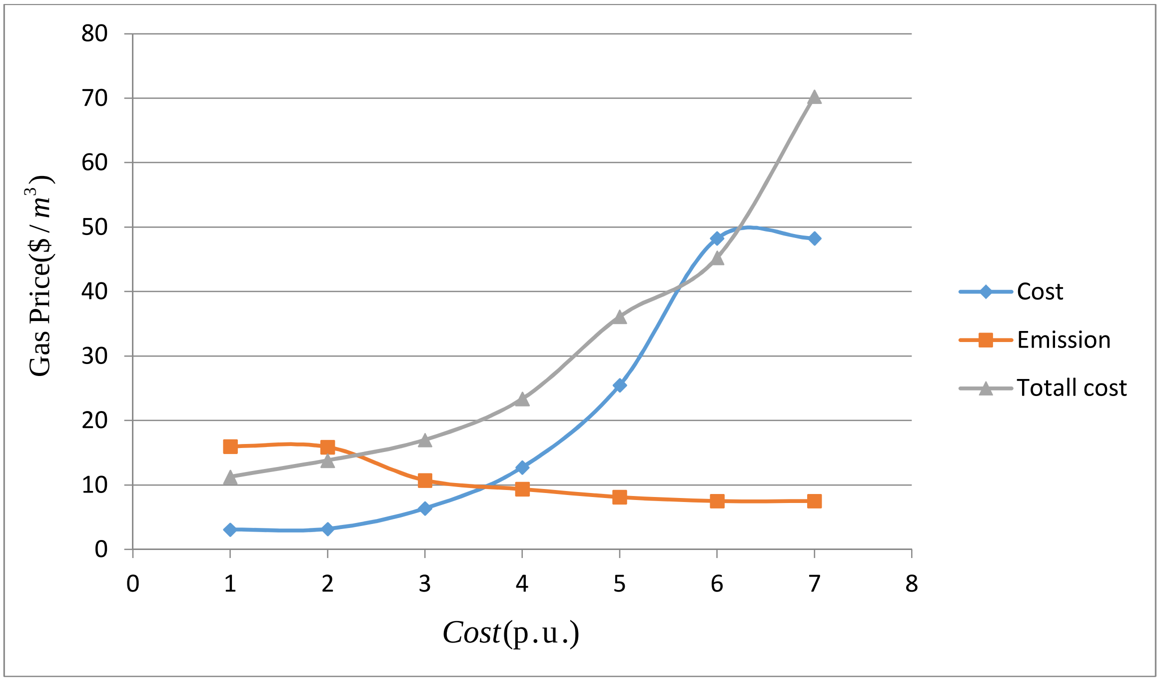

Figure 3. Gas price variation effects on costs

In Table 2, by considering the basic price changes in the cost of gas carriers in accordance with different of weighting factors reviews for cost, greenhouse gas emissions and the total cost.

Table 2. The effect of gas price variations on costs.

	Price×1.8	Price×1.4	Price×1.2	Base Price	Price×2	Price×2.5	Price×3
Cost ($/h)	3.086	3.186	6.372	6.372	25.488	48.256	48.280
Emission (g/kwh)	16.020	15.89	10.7272	10.7272	8.125	7.518	7.518
Total Cost ($/h)	11.261	13.8132	16.9992	23.3712	36.1152	45.264	70.256

Fig. 4 is shown the effects of W variations on generation cost, emission cost and total cost of the objective function during a 24 hour period. In fact, pollution considered as negative yields.

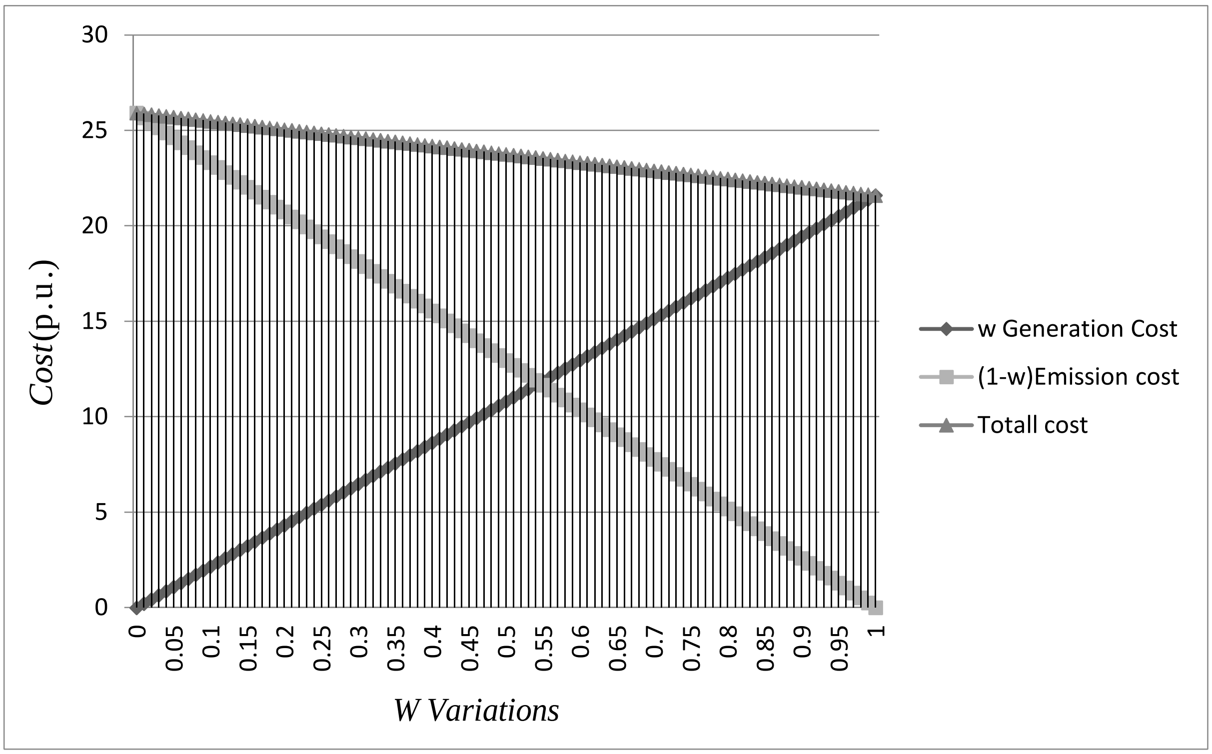

Fig. 4. The W variations effects on generation cost, emission cost and total cost of the objective function during a 24 hour period.

Changes in the cost compared to weighting factor changes are included for the three steps in Fig. 4. In the first step, authors made weighting factor for generation cost in the form of W (black curve), then in second step, the weighting factor made for greenhouse gas emissions cost equal to (W-1) (gray curve). Finally, the total cost that include of generation cost and the emissions cost are made (dark gray curve). In Fig. 4, the values of weighting factor W, there are between amounts of (0, 1) in duration of 0.55.
Table 3 is shown the effects of W variations on generation cost, emission cost and total cost of the objective function during 24 hour period.

Table 3. The effects of W variations on generation cost, emission cost and total cost of the objective function during 24 hour period.

W	W× Generation Cost ($/h)	(1-W)×Emission Cost (g/kwh)	Total Cost ($/h)
25.92	25.92	0.00	0
25.488	23.328	2.16	0.1
25.056	20.736	4.32	0.2
24.624	18.144	6.48	0.3
24.192	15.552	8.64	0.4
23.76	12.96	10.8	0.5
23.328	10.368	12.96	0.6
22.896	7.776	15.12	0.7
22.464	5.184	17.28	0.8
22.032	2.592	19.44	0.9
21.6	0	21.6	1

4.2 The W Variations Effects on Generation Cost, Emission Cost and Total Cost of Objective Function

Aforementioned diagram indicates the relationship among generation cost, emission cost and total cost. If there is no W factor, the diagrams would turn linear in a period of 24 hours because the costs are always constant. This relationship is shown as a bar diagram on each W (is shown in Fig. 4). From the values of the Table 3 it can be seen which one is the optimum state to find the economical working point of the system. For example, for the W = 0.7, generation and pollution cost equal 15.12 ($/h) and 7.776 (g/kwh), respectively.

As well as, as seen in the above figures, is considered the impact parameter as a percentage of the cost of pollution. When the value of this ratio is equal one, means industrial units should not pay any penalty for pollution, but when the coefficient value is equal zero, it means the pollution penalty debate is very important and it is considered. In many papers is mentioned at this subject (Paudyal et al, 2015). Also, The main application of this coefficient is in large industrial cities. When the pollution is under alert status, can be controlled this factor by controlling in obtaining the desired output, and to increase the amount penalty can be controlled pollution and quickly, the system their requirements output supplied by the carrier with lower pollution factor.

For industries in which the generation amount is more significant than pollution, higher may be taken into account. However in the industries with toxic emissions and hazardous pollutions, lower are used to reduce the consumption of toxicity-propagating carriers and increase the alternative carriers such as wind or solar energies.

5. CONCLUSION

Energy hub acts as an energy receiving, converting and storing unit in the consumer side. Variety of equipment such as CHPs), transformers, Boilers, power electronic equipment, energy storage units and etc. are installed inside it based on required output load. The paper have discussed about energy hub optimization problem as a super nude in electrical system in the presence of a storage unit. The paper reduced total cost of system and pollution cost simultaneously. This research has been introduced a new concept of energy hub focusing on the effect of storage. In the first step, authors eliminated storage from the system and all the equations are checked out by GAMS disregarding the storage unit. In the second step, the paper's model include with storage unit. The paper, will see intelligently storage acts to reduce overall system cost. In addition, in this work, the paper were able to get limit of equipment to unpredictable extra costs not logged to system. With changes cost, given that to building infrastructure of equipment, paper need minimum amount of cost (in figures obtained from simulation results on sample hub model clearly presented and the stability is evident in aforementioned figures). Finally, using tables and diagrams of simulation results are obtained selecting the best optimal device that it reduced generation cost, pollution cost and total cost.

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