__Original Research Article__

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

ABSTRACT

Aims: The aim of paper reduces total cost of system, generation cost and pollution cost simultaneously in a proposed model of HUB (multi carrier energy system).
Study design: The case study of the model includes one energy HUB with different characteristics in economic dispatch mode.
Place and Duration of Study: IAU, Iran, November 2014 - February 2016.
Methodology: Model of scenario has obtained through DICOPT solver of GAMS software version 24.1.
Results: Using simulation result of paper have obtained selecting of the best optimal device that has reduced generation cost, pollution cost and total cost.
Conclusion: HUB is a multi-generation system which multiple energy carriers input to the HUB have converted, have stored and have distributed in order to satisfy electrical and heat energy demands. Also, 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 has 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 has considered as negative yields. Also, the paper has presented optimal scheduling by using charging and discharging equations mechanism (effect of storage) has reduced by pollution, generation and total cost simultaneously as objective function in economic dispatch mode.

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

1. INTRODUCTION

The 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, the sector will be central importance for find solutions to the grand challenges ahead (Mancarella, 2014; Shabanpour-Haghighi et al, 2015). With the industry development and the increasing consumption of energy resources, management of energy have become an important issue in different industries now. Moreover, taking into account the serious environmental pollutions made by the manufacturing industries, minimizing these emissions have become very important. Since energy carriers as the raw materials energy producers have a significant role in the cost of energy generation. Increasing need for energy carriers causes the loss of global energy resources. Also, works have presented in the ways to reduction and energy optimization of consumption and cost in the industry.

Increasing energy carriers prices and restrictions fossil resources have been transferred special attention to the energies that capability and greater consistency with the environment also lower cost with higher energy efficiency. Accordingly, many studies have been done. In (Mancarella, 2014) the aim of paper is 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 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), in addition various approaches, criteria for energy, environmental and techno-economic assessment.

In (Parisio and et al, 2012) the control approach using robust optimization (RO) techniques have proposed for a robust optimization problem of energy HUB operations. Simulation result 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, the 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 has 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 has considered as one integrated system of interconnected energy HUBs. Using the model has defined various integrated optimization problems that provides optimal power flow and dispatch approaches are able to estimate the optimal coupling between the energy infrastructure. In (Geidl, 2007) presented an approach for the combined optimization of coupled power flows of different energy carriers. The paper's model is based on distributed energy resources (DERs). The features of the developed technique has demonstrated in a numerical example.

The paper has provided an approach for combining the integrated energy systems (HUB), the environmental pollution and also the effect of ambient temperature. Also, the paper optimized the amount of energy carriers consumed. Moreover, pollutions have minimized according to different strategies of industries. On the other hand, using the procedure has obtained the working point approximation of each equipment. One of another feature of the paper have seen storage systems in the HUB output. Also, in the research to assessment generation, emission and total cost of the objective function during a 24 hour period (economic dispatch mode (ED)) has considered.

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

2. ENERGY HUB CONCEPT

The 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 the thermal demand. Inside the transducer, the electric energy has generated by the transformer and combined heat and power (CHP) output. An amount of electric energy has stored in the transducer by electric storage. The gas energy carrier used as CHP fuel which may produce heat as well as electricity. Fuel carrier may be used to convert fuel to thermal energy. In the output, a thermal storage mounted. The energy HUB has shown in the Fig. 1.

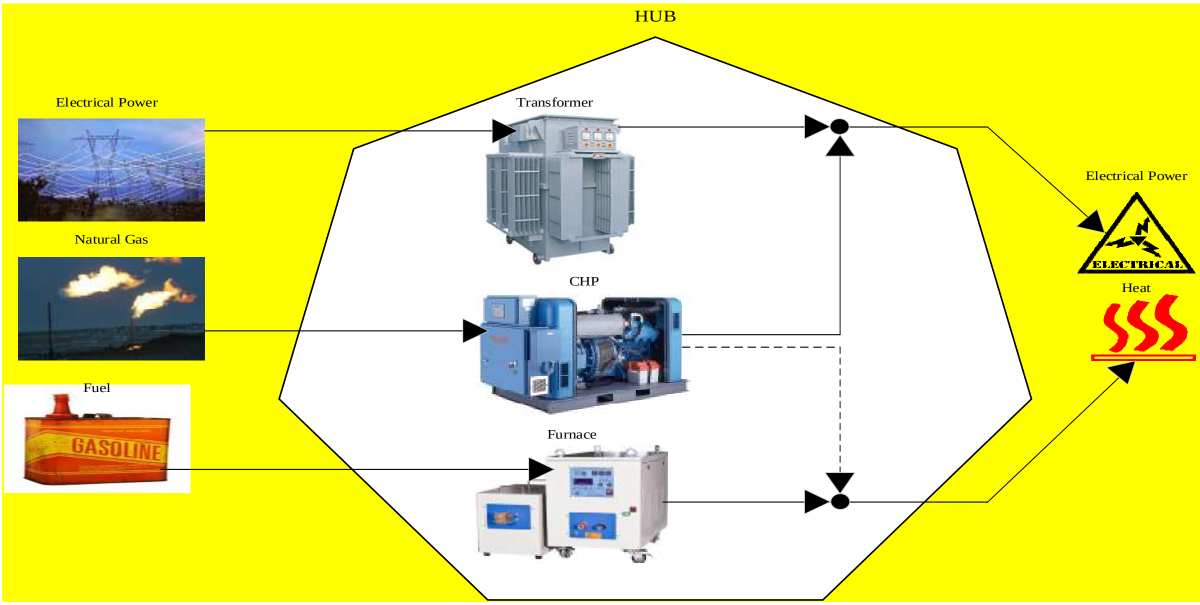

Fig. 1. An integrated energy system (HUB)

3. MATHEMATICAL MODELING

An energy HUB described in Fig. 1 by the following equations. For the system shown in Fig. 1, objective function and constraints equations 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 the effect of storage unit.

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

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

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, electrical, heat and heat furnace efficiencies are denoted η_T, η_{Te}, η_{HE}, η_{F_e} respectively. η_{GT_h} is gas-heat efficiency of gas turbine of CHP. In addition, the electrical load and heat load denoted L_e and L_h respectively. Also, v is dispatch factor.
The equations (1) and (2) may be written as matrices:

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

Totally, equation (3) may be written as:

$$\mathrm{L} = \mathrm{CP} \qquad (4)$$

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

3.2 Inclusion of storage (Geidl, 2007)

The storage includes two parts: the electric storage and the thermal one (isolated water reservoir). With adding storage, equation (4) introduced 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 equations (5) and (6), 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. The storage electrical energy derivative and storage heat energy derivative have shown by $\dot{E}_e(\mathrm{t})$ and $\dot{E}_h(\mathrm{t})$ respectively.

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

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

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

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

The values of E_h and E_e have obtained in the process of optimization by a creative procedure.

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

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

The values $e^{+}_{\mathrm{e}\_charge}$ and $\mathrm{e}^{-}_{\mathrm{e}\_discharge}$ are the 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 have defined as follows:

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

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

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

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

3.3 Storage Systems Constraints

The constraints of the storage electrical and heat systems have shown in equations (13-15):

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

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

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

3.4 Generation Cost

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

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

3.5 Inclusion of Pollution Penalty Impact

The emission cost has shown in equation (17):

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

The coefficients α, β and γ are the coefficients of pollution cost which have determined by air quality control authorities.
The great amount of the pollution made by energy HUB by particulates and toxic emissions. At first, an objective function introduced in this section of the paper which is as follows:
The providing thermal and the electric energy are 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 obeyed profoundly. The factor W is defined to simulate the demand.

3.6 Pollution Cost

The pollution is often produced by toxic emissions from CHP or thermal furnace. In some plants with gas power station, the pollution is from chimneys. The pollution cost function 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

The weighting factor W determines the significance of the pollution to clean energy ratio. In fact, the factor W used to determination the operational constraints of each industrial unit which defines its strategies based on this factor. It has 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 obtained in different temperatures for every particular model of CHP. Afterwards, the temperature variation data on different days of each season have 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. The 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 the pollution and the energy generation costs. Finally, equation of objective function's paper has expressed as follows:

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

4. SIMULATION RESULT

For solving paper's modeling problem, the authors have used 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 divided into four steps. The steps includes step 1: Inclusion the cost in the model without the storage unit. Step 2: Inclusion the emission in the model without the storage unit. Step 3: Inclusion the cost and the saver in the model with the storage unit. Step 4: Inclusion the emission and the saver in the model with the storage unit (blue, orange, gray, and yellow curve shown in Fig. 2, respectively).
At first step, according to the paper modeling (equation (16)) in which the past, noted in the model cost regardless of the storage unit has been considered in the proposed model (Fig. 1). The simulation output in accordance with blue curve is visible in Fig. 2. At second step, according to paper modeling (equation (17)) in which noted in the past. The greenhouse emission, regardless of the storage unit has been considered in the proposed model (Fig. 1). The simulation output in accordance with orange curve is visible in Fig. 2. In the third step, according to the paper modeling (equations (1-4)) mentioned in the past, the impact of the storage costs and simultaneously on the model taking into account the storage unit has been considered in the model (model is more complex than the proposed model). The simulation output in accordance with gray curve is visible in Fig. 2. In the fourth step, according to the 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 have included in the model (model is more complex than the proposed model). The simulation output in accordance with yellow curve is visible in Fig. 2.

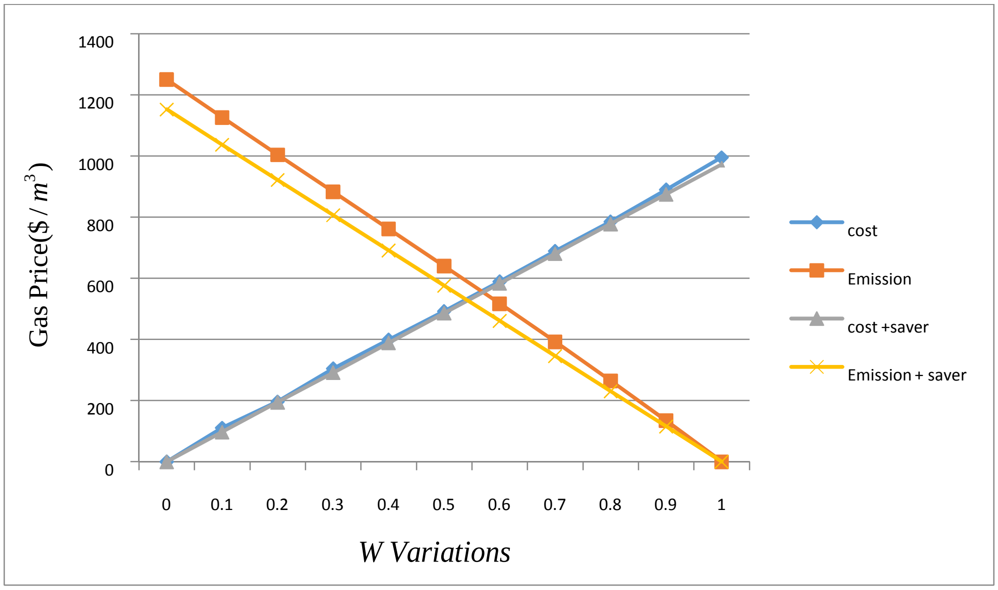

Fig. 2. Investigating of the storage effect.

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

Table 1. Investigation of 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 the numerical values of the storage unit generation, the 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 plus saver mode, and also between emission and emission plus saver mode in amounts of coefficient W because this difference will see with presence of multi-saver in the model.

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

This section includes three steps. Steps include step 1, 2 and 3. Step 1: Inclusion cost in the model and the impact of adding the gas price estimated on other costs (blue curve has shown in Fig. 3). Step 2: Inclusion the emission in the model and the impact of adding the gas price estimated on other costs (orange curve has shown in Fig. 3). Step 3: Inclusion total cost in the model and the impact of adding the gas price estimated on other costs (gray curve has 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 the gas price variations because whatever the price increased. There is still an amount of the thermal load which may need minimum amount of the gas carrier to respond and even if the overall capacity of alternative carriers have used up, they may not be able to respond to the demand.

The 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 the gas carrier price increasing, the system decreases the amount of its consumption automatically. So, the pollutions of the heat and the electricity power station 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 increasing, the 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.

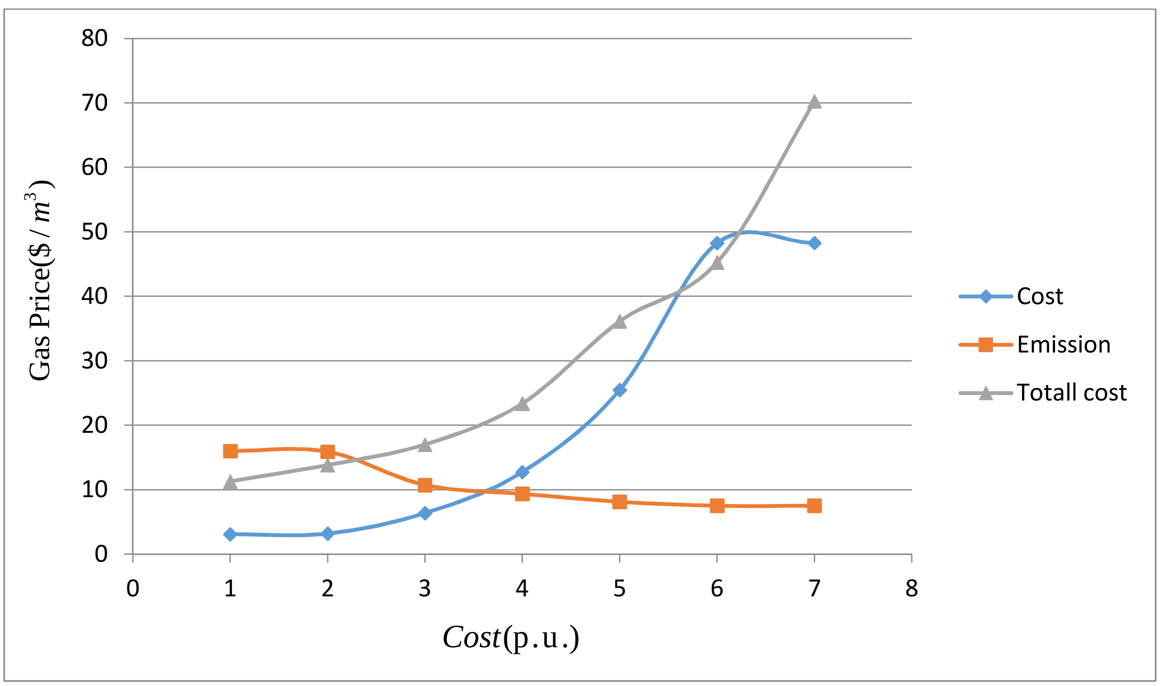

Figure 3. Gas price variations effects on costs

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

Table 2. The effect of gas price variations on the 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 has shown the effects of W variations on the generation, the emission and total cost of the objective function during 24 hour period. In fact, pollution considered as negative yields.

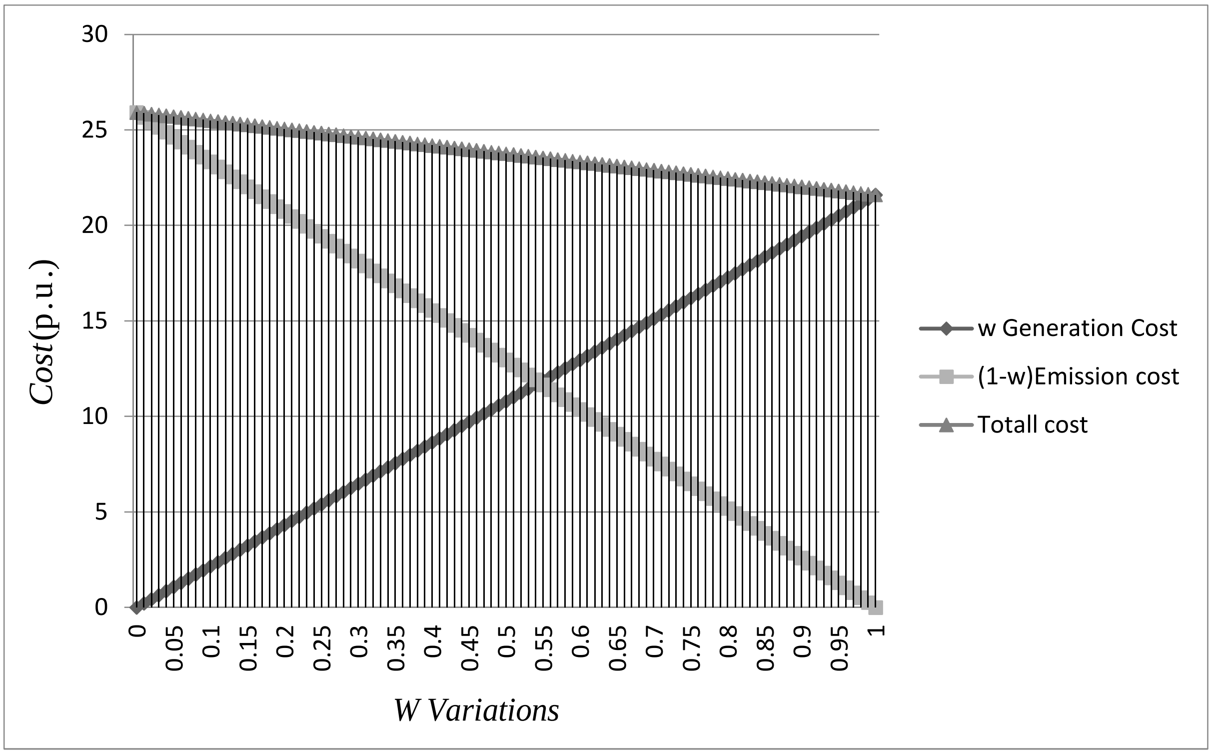

Fig. 4. The W variations effects on the generation, the emission and total cost of the objective function during 24 hour period.

The changes in the cost compared to weighting factor changes included for the three steps in Fig. 4. In the first step, the authors made the weighting factor for the generation cost in the form of W (black curve), then in second step, the weighting factor made for the greenhouse gas emissions cost equal to (W-1) (gray curve). Finally, the total cost that include the generation cost and the emissions cost made (dark gray curve). In Fig. 4, the values of the weighting factor W, there are between amounts of (0, 1) in duration of 0.55.

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

Table 3. The effects of W variations on the generation, the emission 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)
0	25.92	0.00	25.92
0.1	23.328	2.16	25.488
0.2	20.736	4.32	25.056
0.3	18.144	6.48	24.624
0.4	15.552	8.64	24.192
0.5	12.96	10.8	23.76
0.6	10.368	12.96	23.328
0.7	7.776	15.12	22.896
0.8	5.184	17.28	22.464
0.9	2.592	19.44	22.032
1	0	21.6	21.6

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

Aforementioned diagram indicates the relationship among the generation, the emission and total cost. If there is not factor W, the diagrams would turn linear in period of 24 hours because the costs are always constant. This relationship has shown as a bar diagram on each W (is shown in Fig. 4). According to 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, the generation and the pollution cost are equal to 15.12 ($/h) and 7.776 (g/kwh), respectively. As well as, it has considered the impact parameter as a percentage of the cost of pollution, as seen in the above figures. When the value of this ratio is equal to one, means industrial units should not pay any penalties for pollution, but when the coefficient value is equal to zero, it means the pollution penalty debate is very important and they have considered. In many papers have mentioned 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 increasing the amount penalty can be controlled the pollution and quickly, the system their requirements output supplied by the carrier with lower the pollution factor.
For industries in which the generation amount is more significant than the pollution, higher may be taken into account. However in the industries with the toxic emissions and hazardous pollutions, lower has used to reduce the consumption of toxicity-propagating carriers and increasing 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, the energy storage units and etc. have installed inside it based on required output load. The paper have discussed about the energy HUB optimization problem as a super nude in the electrical system in the presence of a storage unit in an economic dispatch mode. The paper reduced total cost of system and pollution cost simultaneously. This research has been introduced a new concept of the energy HUB focusing on the effect of the storage. In the first step, the authors eliminated the storage from the system and all the equations checked out by GAMS disregarding the storage unit. In the second step, the paper's model includes the storage unit. The paper, will see intelligently the 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 the system. With changes cost, given that to building infrastructure of equipment, the paper need minimum amount of the 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 obtained selecting the best optimal device that it reduced the generation cost, the pollution cost and total cost.

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