Original Research Article

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

ABSTRACT

Aims: This paper has reduced total cost of system, generation cost and pollution cost in a proposed HUB (multi carrier energy system) model simultaneously.

Study design: Model design 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 the paper have obtained selecting of the best optimal device that has reduced generation cost, pollution cost and total cost.

Conclusion: The paper will be able to get limit of equipment to unpredictable extra cost not logged to system (it discusses affect the cost of system). This paper has developed a hybrid approach for an integrated energy system, ambient temperature and pollution effects. Therefore, the pollution have saw as output cost of energy HUB. In fact, the pollution has considered as negative yields. Also, the paper has presented optimal scheduling using charging and discharging mechanism equations (effecting of storage) has reduced by the pollution, the generation and total cost as an objective function in economic dispatch mode simultaneously.

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

1. INTRODUCTION

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

The increasing energy carriers prices and restrictions fossil resources have been transferred special attention to the energies that are capability and greater consistency with the environment, and lower cost with higher energy efficiency. Accordingly, many studies have been done in this field. In (Mancarella, 2014) the paper provided to readers with a comprehensive and critical overview of the latest models and assessment techniques that currently are 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) have proposed a control approach using robust optimization (RO) techniques for a optimization problem of energy HUB operations. The simulation result underline the benefits resulting from the application of the proposed approach to an energy HUB structure that designed in Waterloo, Canada. In (Moeini-Aghtaie and et al, 2013) a concept of future energy networks provided 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) this paper presented energy HUB model that 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 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 that are able to estimate the optimal coupling in energy infrastructure. In (Geidl, 2007) presented an approach to combined optimization in different energy carriers of coupled power flows. The paper's model is based on distributed energy resources (DERs). The features of the developed technique has demonstrated in a numerical example.

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

The paper has organized as follows; the energy HUB concepts and a brief overview of energy HUB have presented in section two. Detail formulation of main idea behind the paper, the pollution and cost parameters have defined in section three. The result have debated in detail and effect of storage on cost and the emission of energy HUB has defined in section four. Finally, conclusions are drawn in section five.

2. ENERGY HUB CONCEPT

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

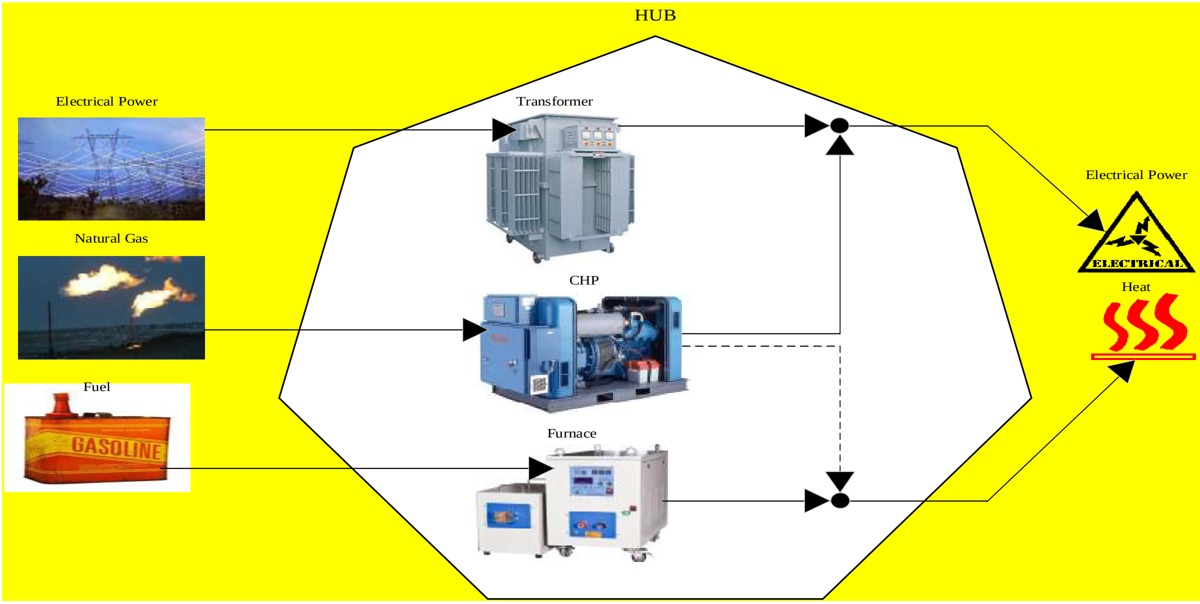

Fig. 1. An integrated energy system (HUB)

3. MATHEMATICAL MODELING

An energy HUB described by the following equations in Fig. 1. In this system that shown in Fig. 1, the 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.

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

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

In equations (1-2), P_e, P_g and P_h are stand for electrical 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 and 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, and v is dispatch factor.
The equations (1) and (2) may be written as matrices:

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

Totally, equation (3) may be written as:

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

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

3.2 Inclusion of the storage (Geidl, 2007)

The storage includes two parts: the electrical storage and the thermal storage (isolated water reservoir). When the authors add the 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 of efficiency if heat generation by CHP, also 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) that 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.

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

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.

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

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

The values $e^{+}_{e\_charge}$ and $\mathrm{e}^{-}_{e\_discharge}$ are 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. In addition, the 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 The Storage Systems Constraints

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

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

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

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

3.4 The Generation Cost

The fixed generation cost has shown by coefficient a. Also, the coefficients 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 in per unit (p.u.). In addition, "Fuel cost" is the price of fuel carrier that used in the furnace in p.u.

$$Generation\ \ Cost = \sum_{t=1}^{24} \left\{ \begin{array}{l} (a + bP_g(t) + cP_g^2(t)) \\ +P_e(t)\,\text{Electrical}\ \ \text{Cost(t)}+ \\ P_{gasoline}(t)\,\text{Fuel}\ \ \text{Csot} \end{array} \right\} (16)$$

3.5 Inclusion of The Pollution Penalty Impact

The emission cost has shown in equation (17):

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

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 with particulates and toxic emissions. At first, an objective function introduced in this section as follows:

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

3.6 The Pollution Cost

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

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

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 determinate the operational constraints of each industrial unit which defines its strategies based on this factor. It has shown as equation (19):

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

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 from the meteorological and related organizations statistically. Therefore, adapting the two diagrams, the paper may find the CHP efficiency in 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 in every hour and enter the efficiency value obtained into the system. The equation of CHP effects are as follows:

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

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

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

4. SIMULATION RESULT

For solving paper's modeling problem, the authors have used DICOPT solver of GAMS version 24.1. DICOPT is a program for solving mixed-integer nonlinear programming (MINLP) problems that involves linear binary or integer variables and linear and nonlinear continuous variables. In Fig. 2, simulation results divided into four steps. The steps include four steps. First step: Inclusion the cost in the model without the storage unit. Second step: Inclusion the emission in the model without the storage unit. Third step: Inclusion the cost and the saver in the model with the storage unit. Fourth step: 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 according 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 according to orange curve is visible in Fig. 2. In 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 according to 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 the 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 according to yellow curve is visible in Fig. 2.

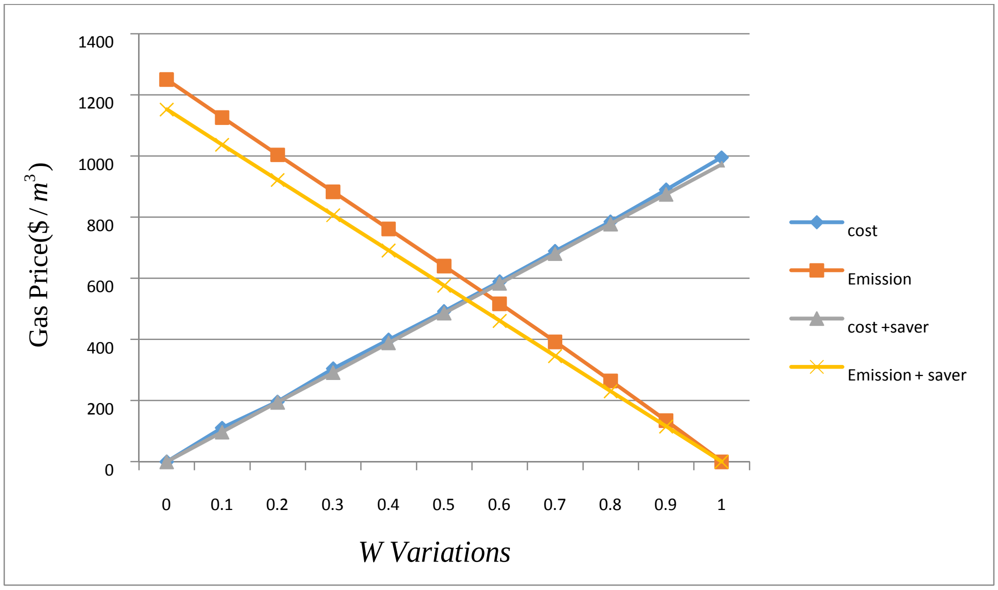

Fig. 2. The investigating of the storage effect.

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. The 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 The inclusion of gas price variations in the costs (W=0.6)

This section includes three steps. Steps include step one, two and three. Step one: the 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 two: the 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 three: the 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, the 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, that's why at 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 some thermal demand. So, with respect to the 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 costs.

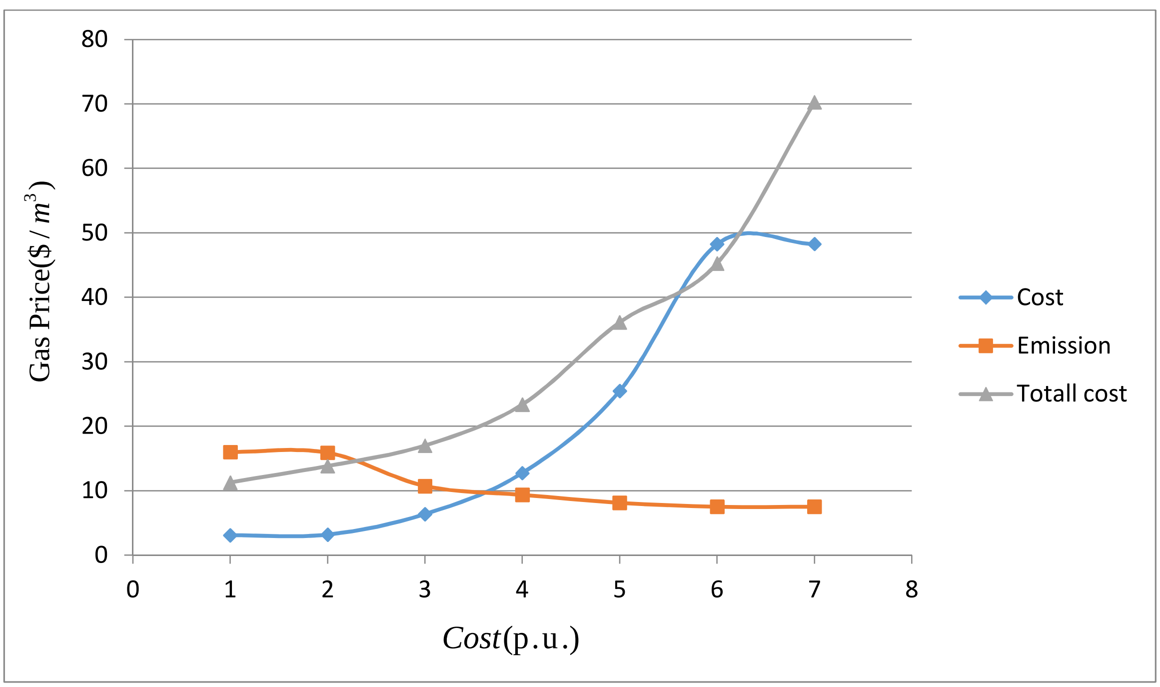

Figure 3. Gas price variations effects on the costs

In Table 2, by considering the basic price changes in the cost of gas carriers in according to 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 in during 24 hour period. In fact, the pollution considered as negative yields.

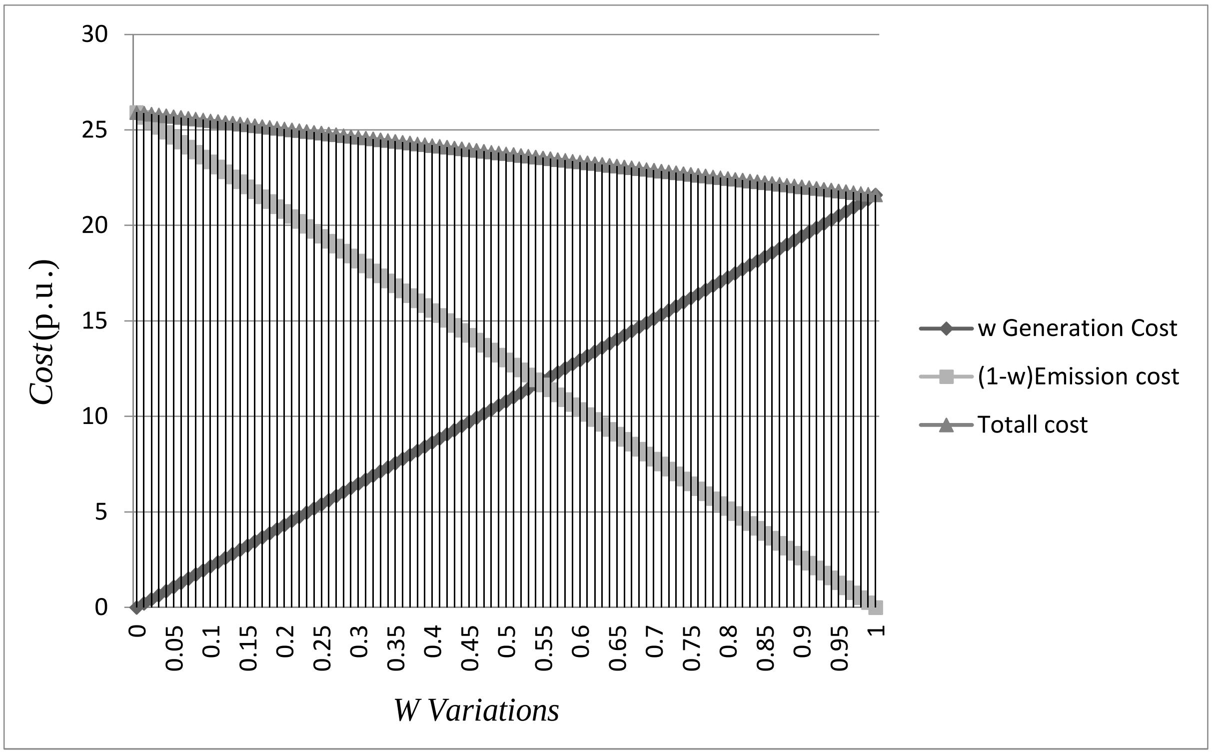

Fig. 4. The W variations effects on the generation, the emission and total cost of the objective function in during 24 hour period.

The changes in the cost compared to weighting factor changes included for the three steps in Fig. 4. In first step, the authors made the weighting factor for the generation cost in a 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 includes 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 in 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 hour because the costs always are constant. This relationship has shown as a bar diagram on each W (it 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 operating point of the system. For example, for W = 0.7, the generation and the pollution cost are equal to 15.12 ($/h) and 7.776 (g/kwh), respectively. Also, as seen in the above figures, it has considered the impact parameter as a percentage of the cost of pollution. When the value of this ratio is equal to one, it 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 control it in obtaining the desired output. For the 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

The 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 and the energy storage units, etc. have installed inside it based on required output load. This paper have discussed about the energy HUB optimization problem as a super nude in the electrical system with 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 the storage acts to reduce overall system cost intelligently. In addition, in this work, the paper were able to get limitation 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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