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Optimizing Energy Management in Energy Hub Considering Pollution and Storage Effects

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Abstract

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 purpose reduce total cost of system and pollution cost simultaneously. 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 were 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 effects of pollution. Therefore, saw pollution as output cost energy hub. In fact, pollution considered as negative yields. As well as, the paper presented optimal scheduling by use charging and discharging equations mechanism (effect of storage) reduced by both pollution, generation cost and total cost simultaneously as objective function in 24 hours. Numerical results approved through DICOPT of GAMS software.

Keywords: Energy Storage, Multi Carrier Energy Systems (Hub), Optimizing Energy, Pollution Effects

Introduction

Climate change and energy security are among the central parameters that 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 of central importance for finding solutions to the grand challenges ahead (Mancarella, 2014). 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 reduce cost in the industry.

With increasing energy carriers prices and restrictions fossil resources, special attention to the energies that have been transfer capability and greater compatibility 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 energy hubs, micro grids (MGs), and VPPs (virtual power plants), as well as various approaches and criteria for energy, environmental, and techno-economic assessment.

In (Parisio and et al, 2012) a control approach using robust optimization (RO) techniques is 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 presents 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 this model, is defined various integrated optimization problems that provides optimal power flow and dispatch approaches and 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 papers model is based on distributed energy resources (DERs). The features of the developed technique are demonstrated in a numerical example.

This research provides an approach for combining the integrated energy systems (Hub) and 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 is 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.

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 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 Figure 1.

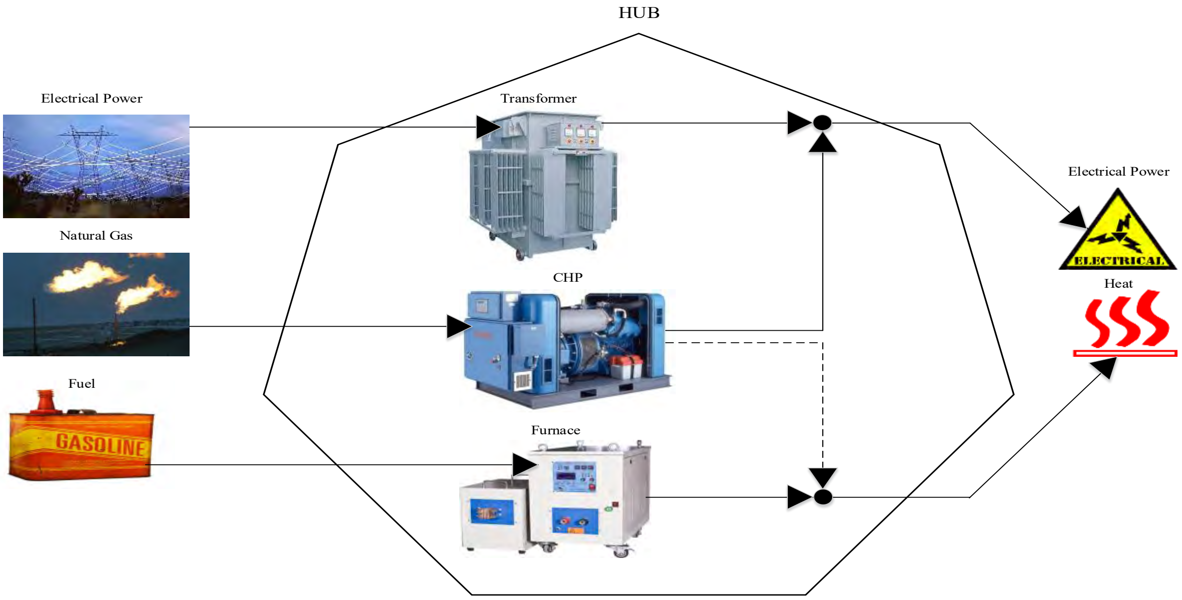

Figure 1. An integrated energy system (Hub)

Mathematical Modeling

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

Process lack of Storage Unit (Maroufmashata and et al, 2015)
The following equations ((1) – (12)) described about affect 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 this equations, 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 above equations may be written as matrices:

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

Totally, (3) may be written as:

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

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

Inclusion of storage (Geidl, 2007)

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

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

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

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 that (Geidl, 2007) takes into account a heat storage on the input and a battery on the output, so athour 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 describes 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.

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

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

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

Also, constraints of bounds are defined as:

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

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

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

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

Storage Systems Constraints

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

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

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

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

Generation Cost

Fixed generation cost is shown by a Also, b and c are variable cost and operation cost of CHP. "Electrical cost" is the price of energy carrier purchased from the grid per-unit. "Fuel cost" is the price of fuel carrier in per unit of fuel used in the furnace.

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

Inclusion Impact of Pollution Penalty

Emission cost is shown in following equation:

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

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.

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:

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

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

Exert Influence of W

W is a weighting factor which 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 below:

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

Inclusion of Ambient Temperature Effect on CHP Performance

In order to determine the effect of temperature on CHP performance, the data concerning CHP performance is obtained in different temperatures for every particular model of CHP. Afterwards, the temperature variation data on different days of each season is 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 effect is as follows in (20):

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

In (6), 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.

Simulation Results

For solve problem of paper's modeling, authors used from DIPOCT solver of GAMS software version 24.1. In figure 2 simulation results 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 figure 2, respectively).
At first step, according to paper modeling relationships (16) which in the past noted, models cost regardless of the storage unit has been considered in the proposed model (figure 1). Simulation output in accordance with blue curve is visible in figure 2. At second step, according to paper modeling relationships (17) which noted in the past. Greenhouse emission, regardless of the storage unit has been considered in the proposed model (figure 1). Simulation output in accordance with orange curve is visible in figure 2. In the third step, according to paper modeling relationships (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 is more complex than the proposed model). Simulation output in accordance with gray curve is visible in figure 2. In the forth step, according to paper modeling relationships (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 is more complex than the model proposed). Simulation output in accordance with yellow curve is visible in figure 2.

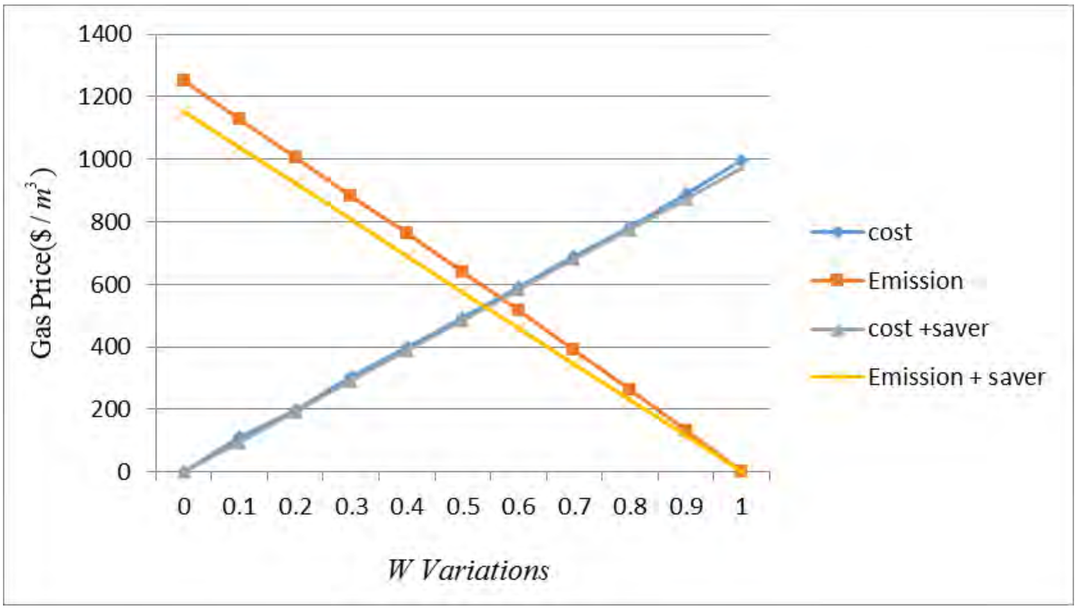

Figure2. Investigating the storage effect.

Table 1 shows the weighting factor changes in the objective function (19) with respect lack of storage units in the proposed model and its impact on generation costs, greenhouse gas emissions, and total cost. Results of table 1 shows the improved numerical values of a storage unit generation, greenhouse gas emissions and total costs in the proposed model.

Table 1. Investigation the storage effects

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

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

Figure 3 includes 3 steps. Steps includes step 1: inclusion cost in the model and impact of adding the gas price is estimated on other costs, step 2: inclusion emission in the model and impact of adding the gas price is estimated on other costs, step 3: inclusion total cost in the model and impact of adding the gas price is estimated on other costs, (blue, orange, and gray curve shown in figure 3, respectively). According to the figure 3, gas price increase may heighten other costs. However, from there on, no increment occurs on the diagrams with gas price variation, 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 graph has a very gentle slope. The reason is that, first with a gas carrier price increase, the system decreases automatically the amount of its consumption. So, that the pollutions of heat and electricity power station are lowered. However, the pollution is never 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. 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.

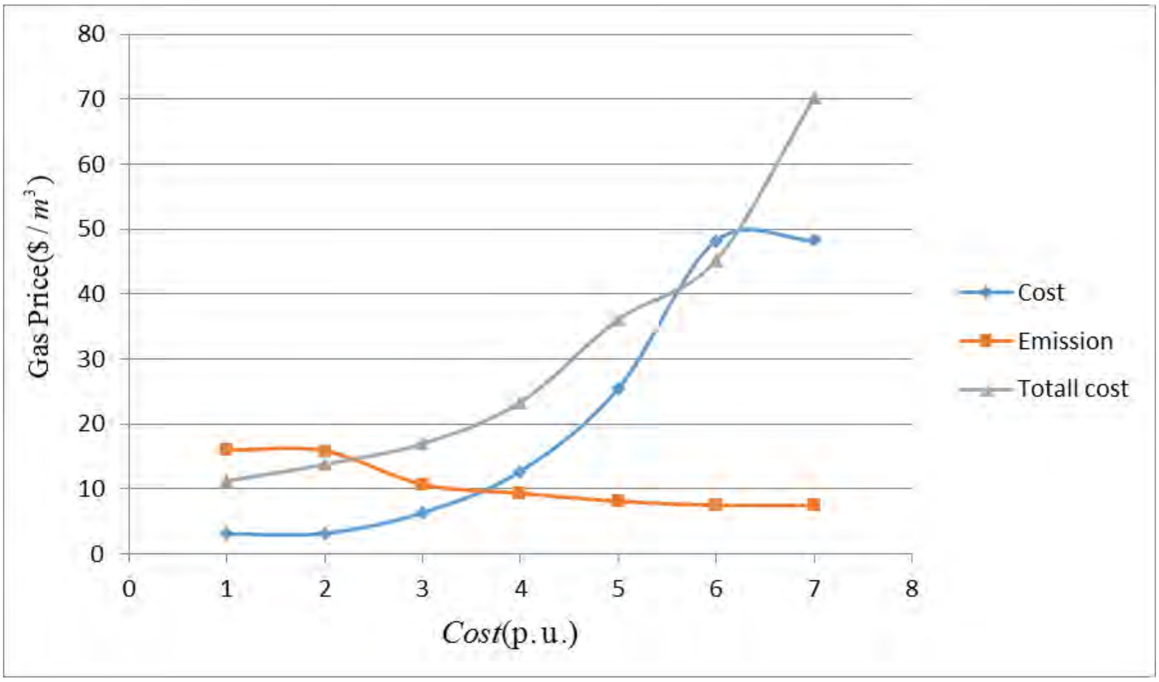

Figure 3. Gas price variation effects on costs

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

Figure 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.

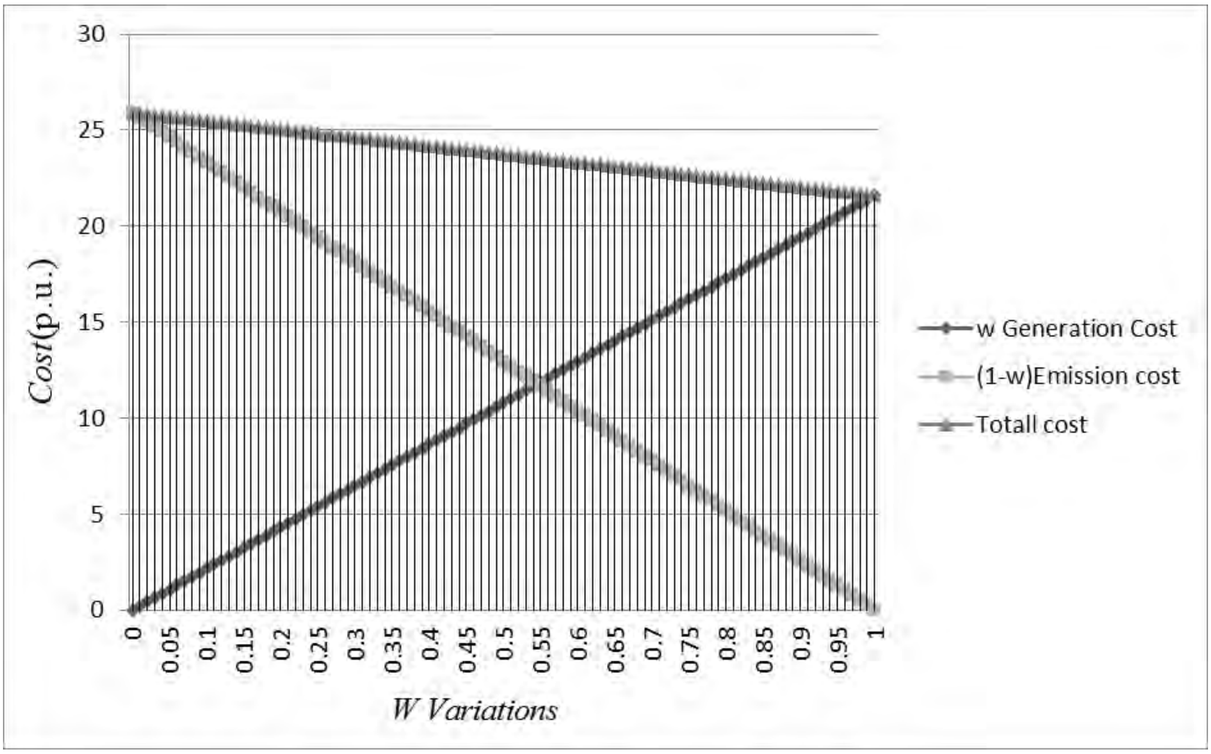

Figure 4. The effects of W variations on generation cost, emission cost and total cost of the objective function during a 24 hour period.

Changes in the cost compared to weighting factor changes are included for the three steps in figure 4. In the first step, author 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 cost of greenhouse gas emissions cost are made (dark gray curve). In figure 4, the values of weighting factor W, there are between (0, 1) in duration of 0.05.

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

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

W	W× Generation Cost ($/h)	(1-W)×Emission Cost (g/kwh)	Total Cost ($/h)
25.92	25.92	0	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

W variations effects on generation cost, emission cost and total cost of objective function

Aforementioned graph indicates the relationship among generation cost, emission cost and total cost. If there is no W factor, the graphs would turn linear in a period of 24 hours because the costs are always constant. This relationship is shown as a bar graph on each W (shown in figure 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 costs 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 1, means industrial units should not pay any penalty for pollution, but when the coefficient value is zero, it means, the pollution penalty debate is very important and is considered. The main application of this coefficient is in large industrial cities. When that 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.

Conclusion

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 purpose reduce 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, we eliminate 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. As well as, 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 obtain selecting the best optimal device that it reduces generation cost, pollution cost and total cost.

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