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Investigating and identifying the factors affecting the efficiency of gas power plants affiliated with Sistan-Baluchistan regional electricity company

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Abstract: Considering the present economic situation in Iran, the problem of the energy consumption is very important and, hence, identifying the factors affecting the energy production is vital too. Therefore, designing an appropriate model and a dynamic process for investigating and identifying the factors affecting the turbine efficiency in producing energy is quite necessary. Effort has been made in this paper to identify and rank the factors affecting the gas turbine efficiency using a combinatorial model consisting of the Data Envelopment Analysis (DEA) and Analytic Hierarchical Process (AHP) models. Considering the related inputs and outputs, the Fog factor, with 95% production efficiency, has had the highest ranking among all the other factors.

Key words: *Gas turbine efficiency; Analytic hierarchical process; Data envelopment analysis*

1. Introduction

Considering various domestic, commercial, industrial, and agricultural energy needs, the electrical energy consumption is day-increasing and *Iran's* annual need is growing. Since nearly 70 years ago, gas turbines have been used to produce electricity. Combustion with very high temperature and pressure produces gases which expand in different layers of fixed and moving blades and produce power. The first design of a gas turbine (similar to the present ones) was by *John Payer* in 1791. Finally, in early 20th century, after extensive studies, the first practical gas turbine

Consisting of a multi-layer reaction turbine and a multi-layer axial compressor was produced (Walsh and Fletcher, 2000). This turbine was used in a steel mill in Germany in 1933, and the most recent one with a power of 212.2 mw has been installed and utilized in France (Zuhair and Adam, 2006). Since the gas turbine is quite important and is extensively used in different industries, much research has been done to improve its efficiency. In this regard, mention can be made of the paper presented by A. Polices who introduced different gas turbine cycles and their efficiencies (Poullikas, 2005). In another paper, *Sullerey* and *Agarwall* studied the methods of improving the efficiency of gas turbine cycles (R.K Sullerey and Agarwal, 2006). *J. Horlog* of Cambridge University explained in a book entitled "Advanced Gas Turbine Cycles" the new cycles of gas turbines (Horlog, 2003).

The need for the improvement of the output power and efficiency of the new gas turbines is increasing, and this has led to much effort to improve the operations of different turbine components.

Considering the mentioned objectives, the following questions are to be answered in the present paper:

1- What are the factors that most affect the efficiency of gas turbines?

2- Which is the factor, considering the climatic conditions in *Sistan-Baluchistan* Province, that most affects the efficiency of gas turbines?

3- What is the ranking of the factors that affect the improvement of the efficiency of Zahedan Gas Power Plant turbine (*Zahedan* is the center of *Sistan-Baluchistan* Province)?

This paper begins with evaluating the effective factors with DEA and ends with prioritizing these factors with AHP.

2. The DEA/AHP process

To solve the problem of identifying the factors affecting the improvement of the efficiency of the gas power plants affiliated with *Zahedan Regional Electricity Company*, we have used in this paper a combinatorial DEA/AHP model which has a 2-step process, i.e. 1) a DEA model is solved for every pair-factors without considering other factors, and 2) a level 1 AHP model is solved to fully rank the factors using the results in step 1 and forming a matrix of the pair-comparisons (Martin,E,2003). The first step in the formation of the pair-comparisons matrix is using the DEA model for each A/B pair and the CCR classic model shown belo

$$Max\ Z_{AA} = \frac{\sum_{r=1}^{s} u_r y_{rA}}{\sum_{i=1}^{m} V_i x_{iA}}$$

S.t

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$$\frac{\sum_{r=1}^{S} u_r y_{rA}}{\sum_{i=1}^{m} V_i X_{iA}} \leq 1 \quad (1)$$
$$\frac{\sum_{r=1}^{S} u_r y_{rB}}{\sum_{i=1}^{m} V_i X_{iB}} \leq 1$$
$$u_r V_i \geq 0 \quad r = 1,2,\dots,s,i,\dots,m$$

To linearize the above model, $\sum_{r=1}^{m} u_r y_{rA}$ has been taken equal to 1; the linearized model is as follows:

$$E_{AA} = Max\ Z_{AA} = \sum_{r=1}^{0} u_r y_{rA}$$

S.t

$$\sum_{i=1}^{m} V_i X_{iA} = 1 \quad (2)$$
$$\sum_{r=1}^{S} u_r y_{rA} \leq 1$$
$$\sum_{i=1}^{s} u_r y_{rB} - \sum_{i=1}^{m} V_i x_{iB} \leq 0$$
$$u_{r,} V_i \geq 0 \quad r = 1,2,\dots,s,i,\dots,m$$

To find the cross-efficiency, the following model is solved:

$$E_{AA} = Max\ Z_{BA} = \sum_{i=1}^{s} u_r y_{rB}$$

S.t

$$\sum_{i=1}^{m} V_i X_{iB} = 1 \quad (3)$$
$$\sum_{r=1}^{S} u_r y_{rB} \leq 1$$
$$\sum_{i=1}^{s} u_r y_{rA} - E_{AA} \sum_{i=1}^{m} V_i x_{iA} \leq 0$$

Accordingly, 4 problems are solved and E_{AA}, E_{BB}, E_{BA}, and E_{AB} are calculated (Martin, 2003).

Using the results of the AHP model, the diagonal factors of the matrix are found to be equal to 1 and the following relation is true for any a_{ij} factor:

$$a_{ij} = \frac{E_{ii}+E_{ij}}{E_{jj}+E_{ji}} \quad (4)$$

In the pair-comparison matrix of the AHP model, the diagonal factors are 1 and for any factor the relation $a_{ij} = 1/a_{ji}$ is true.

In the original AHP model, the data of the pair-comparison matrix are objective (i.e. they are the decision maker's priorities), and to overcome this problem, we first use DEA for pair-comparisons and then AHP for final ranking. Therefore, combining two DEA and AHP models, we eliminate the objective tensions in pair-comparisons of the choices and criteria, and carry out the full ranking of the decision making factors through the use of DEA. In fact, the DEA/AHP combination enjoys the merits of both models, but does not have any of their limitations (Cai and Wu, 2001).

3. Ranking with AHP

i) The sum of the numbers in every column of the pair-comparison matrix is calculated.
ii) Every factor is divided by the sum of that column and a new normalized matrix is formed.
iii) The average of the factors of every row of the normalized matrix which shows the rank weight of every factor is calculated.

The statistical population used in the present paper includes 8 gas power plants in Sistan-Baluchistan Province, Iran, in every row of which one factor has been used. The factors are as follows:
i) New hot gas components, ii) Renovated hot gas components, iii) Observing the instructions regarding the proper utilization and assembling, iv) Fog, v) Media cooling, vi) Pure fuel utilization, vii) Timely repairs, viii) Cold-air injection.

After data gathering and determining the criteria, indexes, and the costs of factors that affect the gas turbine efficiency, and entering them as the inputs to the Lingo, Expert Choice, and SPSS software, the analysis is done and the useful outputs (factors' efficiencies) are calculated. Fig. 1 can help a better understanding of the distribution of the selected data in *Zahedan* gas power plants.

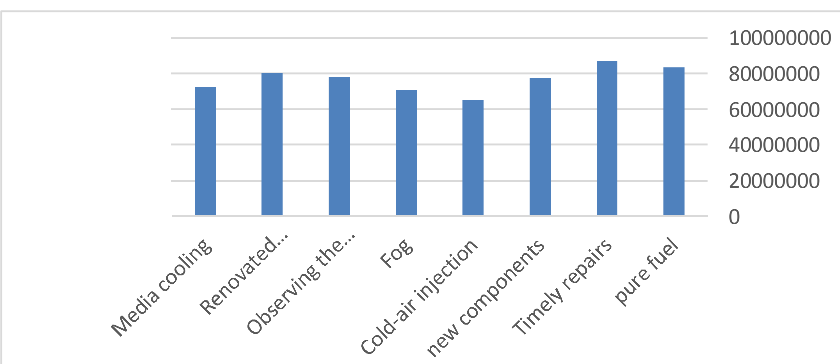

Fig. 1: Fuel consumption (first input) for different units

In this paper, use has been made of: 1) the Lingo software to evaluate the factors affecting the gas turbine efficiency and solve the DEA problem, 2) the SPSS software to graphically analyze the facts and figures, and 3) the Expert Choice software to rank and prioritize the factors that affect the efficiency of gas turbines.

4. Results

In previous sections, we discussed the steps to be considered in designing a combinatorial DEA/AHP model. Now, we are going to explain an example of such a combination in one of the province's gas power plant units.

The first input is the amount of the fuel consumed by the gas turbine to produce the gross electrical energy that, considering the turbine efficiency calculation formula, has a vital role in the turbine output (gross production). The second input is the total cost incurred for the execution of the factors defined in Table 1. These 2 inputs determine the Table inputs meaning that how much should be spent and how much fuel is consumed for energy production if any of the factors affecting a gas turbine unit is executed.

In Table 1, the first output is the gross production of the gas turbine. The second and the third outputs of the Table are CC/Kw (CC-based fuel consumption for the production of 1 Kw of gross electrical energy) and the efficiency respectively.

To answer question 1 (asked in section 1), the following factors are shown in Table 1:

Table 1: Input/output indices of gas turbine units

Factors	Fuel consumed	Costs (Tooman)*	Gross production	CC/Kw	Efficiency (%)
pure fuel	83446528	1000000000	231140	228053	24
Timely repairs	87198592	880000000	214154	240204	23.5
new components	77397371	860000000	212957	222534	23.5
Cold-air injection	65285178	920000000	231140	264016	24
Fog	70788550	800000000	226189	255710	23.5
Observing the instructions	78424090	890000000	218638	212654	22
Renovated components	80365259	870000000	216795	222668	22.5
Cold-air injection	72569172	840000000	223601	230864	23

*One Tooman equals 10 Rials and Rial is the currency of IranUsing the data in Table 1, we will have:

The first input of effective factor 1 × V_1 + its second input × V_2 = 1

The first output of effective factor 1 × U_1 + its second output × U_2 + its third output × $U_3 \leq 1$

The first output of effective factor 2 × U_1 + its second output × U_2 + its third output × U_3 – (the first input of effective factor 2 × V_1 + its second input × V_2) ≤ 0

Using the input/output table of Zahedan gas power plant units and the Lingo software, the pair-comparisons are performed with the DEA model as follows:

$E_{MM} = Max$

MODEL:

MAX= $231140 \times U1 + 228053 \times U2 + 24 \times U3$;

$83446528 \times V1 + 1000000000 \times V2 = 1$;

$231140 \times U1 + 228053 \times U2 + 24 \times U3 <= 1$;

$214154 \times U1 + 240504 \times U2 + 23.5 \times U3 - (87198592 \times V1 + 880000000 \times V2) <= 0$;

END

Now, we can start ranking with the AHP model. The calculations regarding the determination of the priority of every decision factor using the data of the pair-comparison matrix are some mathematical formulations briefly presented in this paper.

Next, using Table 1, we will find the sum of all the numbers in every column and show it at the bottom of that column.

Now, after finding the sum of the numbers of every column of the pair-comparison matrix in Table 2, every factor of the column is divided by the mentioned sum; the new matrix thus found is called the normalized comparisons matrix

Now, to rank the effective factors, we should arrange the relative weights of the gas units' effective factors so as to find the final weight to answer questions 2 and 3 asked in section1.

4.1. Results analyses

The data and information found for 8 factors affecting *Zahedan* gas power plant units have been analyzed and investigated in this part of the paper. After DEA/AHP operations, the ranking of the effective factors was done based on the allotted weights. The highest effect was that of fog; media cooling, cold-air injection, renovated hot gas components, observing utilization instructions, new hot gas components, timely repairs, and pure fuel ranked second to eighth respectively. The results of the evaluation of different operational factors carried out by the SPSS software, considering the important output indices and their efficiencies, are shown in Fig.2.

Table 2: Pair-comparisons

Factor	Pure fuel	Timely repairs	New hot gas components	Cold-air injection	Fog	Observing utilization instructions	Renovated hot gas components	Media cooling
Pure fuel	1	1	1	0.92	0.866879	1	1	0.90746
Timely repairs	1	1	1	1	0.909091	1	1	0.99163
New hot gas components	1	1	1	1	0.930233	1	1	0.997978
Cold-air injection	1.086956	1	1	1	1	1	1	1
Fog	1.153563	1.099999	1.074999	1	1	1	1	1
Observing utilization instructions	1	1	1	1	1	1	0.97891	1
Renovated hot gas components	1	1	1	1	1	1.021544	1	1
Media cooling	1.101976	1.008440	1.002026	1	1	1	1	1

Table 3- Final ranking of the effective factors

Rank	Effective factor	Rank weight
1	Fog	0.129960
2	Media cooling	0.126646
3	Cold-air injection	0.126260
4	Renovated hot gas components	0.125293
5	Observing utilization instructions	0.124626
6	New hot gas components	0.123793
7	Timely repairs	0.123350
8	Pure fuel	0.120070

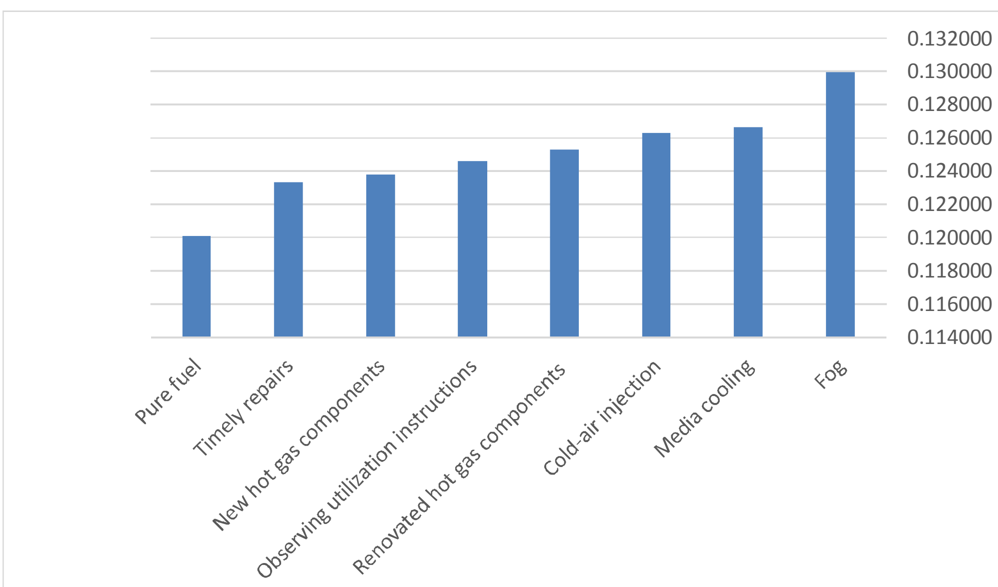

Fig. 2: Ranking of the effective factors

Almost all the calculations related to the AHP are carried out based on the initial judgment of the decision maker which shows itself in the form of the pair-comparison matrix, and any type of error and incompatibility in the comparisons and prioritization among the choices and indices can falsify the computations' final results. The compatibility ratio is a means of specifying the compatibility of the judgments and shows the trustworthiness of the matrix prioritizations. In this paper, the compatibility ratio has been found by the Expert Choice software based on the following steps:

1- Calculating the total weight factor
2- Calculating the compatibility vector
3- Calculating the value of λ_{max}
4- Calculating the compatibility index
5- Calculating the compatibility ratio

In this paper, the compatibility ratio was found to be 0.1 which shows that the comparisons are compatible and, hence, the ranking found by DEA/AHP model is fully validated.

5- Conclusions

As shown, the first step in evaluating the improvements of the processes of an organization is to select a model appropriate to the criteria, factors, and units the decision makers want to assess. Since such models have their own merits and demerits, a combinatorial model can complete the evaluation process and help the decision makers to evaluate the operations of the organization more precisely.

A feature of the DEA/AHP combinatorial model, compared with other models, is its realistic evaluation. From among different units of an organization, it introduces some as efficient and finds, through them, the efficiency border, and then takes this as a basis for the evaluation of other units. In this assessment, units are not considered inefficient because they do not comply with a predefined standard level they are so because their operations, compared with those of the similar efficient units in the same organization, are weak. Another important feature is the simultaneous evaluation of a set of factors; DEA models evaluate input/output factors simultaneously and do not have only-single-input/output limitations.

As mentioned before, use was made, in this paper, of the Data Envelopment Analysis (DEA) model for the evaluation, and the Analytic Hierarchical Process (AHP) for the ranking of the factors affecting gas turbines; the highest rank with an appropriate production efficiency, considering the related input and output, was that of the fog factor; media cooling, cold-air injection, renovated hot gas components, observing utilization instructions, new hot gas components, timely repairs, and pure fuel ranked second to eighth respectively.

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