The Application of Solid Oxide Fuel Cell for Power Generation in Iran:
Feasibility and Cost Analysis

Mohammad Ameri*, Mohammad J. Heidari

Energy Engineering Department, Power & Water University of Technology, Tehran, Iran

*Author to whom correspondence should be addressed, email: ameri_m@yahoo.com

Abstract: In the current world, the energy resources of a country are the key assets for that country. Since a long time ago, fossil fuels are the main energy carriers and are used in steam turbine, gas turbine and combined cycle power plants for electrical power generation. The increase in the application of fossil fuel resources and reduction of these energy resources as well as other factors such as CO₂ emission and environment pollution has enhanced the utilization of new technologies in using these valuable resources. In this paper, one of these new technologies i.e. fuel cell, is studied and the application of solid oxide fuel cells in cogeneration plants in Iran is assessed. This evaluation is based on the calculation of cost of electricity (COE) using this technology and comparison of it with the other conventional technologies cost. Also, the effects of various parameters on the cost of electricity are investigated. The calculations have been done for the present and future conditions. The results have shown that the fuel cell technology is not economical at present and it can not compete with the conventional technologies. However, this option will be an economical and suitable alternative in comparison with the other conventional technologies for power generation with respect to the near future fuel cells mass production, capital cost reduction, lifetime increase, emission importance and fossil fuel price increase.

Keywords: Power Generation, Solid Oxide Fuel Cell, Cost of Electricity (COE), Capital Cost, Sensitivity Analysis

Introduction

From the viewpoint of primary energy resources, Iran has strategic conditions in the world. This country has the largest resources of crude oil and natural gas after Saudi Arabia and Russian Federation respectively [1]. The major part of oil consumption in Iran has occurred in the transportation sector. Also, the largest part of natural gas consumption has occurred in domestic and power generation sectors. As Iran has great resources of natural gas, the generation of electricity from this energy carrier
in the power plants has been the policy of the government. In fact the ratio of power generation from gas to the total power generation in Iran ranks first in the world [1]. Electrical power consumption in Iran was around 131190.4 kMWh in 2004 with the overall installed capacity of 37,300 MW, indicating a high annual growth rate of 8.7% in that year [2]. Based on the rate of population growth in Iran, increase in urbanization, industrial and economical development and improvement of the lifestyle, the power consumption will increase very fast in the future. At present the additional power plants are usually gas turbine and combined cycle types. The objective of this paper is to present the result of a feasibility study and cost analysis regarding the application of the fuel cell power plants in Iran.

In the fuel cell power plants, the fuel cell stack is utilized for power generation and for heat production in suitable conditions. Any kind of fuel cells can be applied for power generation. Some of them are Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), Alkaline Fuel Cell (AFC), Direct Methanol Fuel Cell (DMFC), Polymer Electrolyte Fuel Cell (PEFC), and Solid Oxide Fuel Cell (SOFC). Regarding the technical perspective and predictions about development and commercialization of fuel cells, solid oxide fuel cells (SOFC) and polymer electrolyte fuel cells (PEFC) are better options than other fuel cell types [3]. The PEFC is the best option for substituting the internal combustion engines due to its low operational temperature (about 80°C). However, SOFC is the main candidate for cogeneration in the fuel cell power plants. The solid oxide fuel cell is an emerging technology with the ability to provide combined heat and power due to its high operational temperature (about 800°C) [4]. The produced heat can be used for heating purposes or for improving the electrical efficiency by combination with micro gas turbine. The electrical efficiency of solid oxide fuel cell is about 40 to 55% and the overall efficiency (with heat utilization) is about 80 to 90% [5]. One of the significant advantages of SOFC is that they can be directly fuelled by hydrocarbon fuels and particularly by natural gas. Therefore, the solid oxide fuel cell will be a very attractive option for the rich natural gas countries such as Iran.

On the other hand, the high efficiency of this technology can reduce the amount of released CO₂ and cause the reduction of pollutant in the atmosphere. Also, the nonexistence of moving parts in this system can reduce the sound pollution. Due to these reasons, the fuel cell power stations can be installed near the cities. Therefore, the transmission and distribution costs and their losses will be reduced [5]. The modular characteristic of fuel cell power stations is another attractive option. In fuel cell power stations the capacity can be increased easily by adding fuel cell stacks.

However, solid oxide fuel cells have some disadvantages. For example, the high operational temperatures cause thermal stresses and reduce the lifetime of system. The high capital cost of this technology is still the main problem in the development of fuel cells. The efficient lifetime of SOFC is 5 years at full load operation. However, one may predict that the lifetime of this technology will reach to 10 years in the near future [4].

On the other hand, the high capital cost of this technology is still the main problem in development of fuel cells. The present capital cost of solid oxide fuel cell is about 3000 US $/kW. However, the estimates show the reduction of the costs to 500 US $/kW in the near future. The current operation and maintenance (O&M) cost of SOFC is high (about 0.025 US cents/kWh) and can be reduced to around 0.01 US cents/kWh in future. These advantages and disadvantages are listed in table 1. With respect to advantages and disadvantages, the fuel cell power stations can be a very suitable alternative for conventional power generation technologies particularly for the countries such as Iran.
Table 1 Advantages and disadvantages of solid oxide fuel cells

<table>
<thead>
<tr>
<th>advantages</th>
<th>disadvantages</th>
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<tr>
<td>high efficiency</td>
<td>high capital cost (at present)</td>
</tr>
<tr>
<td>ability of cogeneration</td>
<td>high O&amp;M cost (at present)</td>
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<tr>
<td>direct natural gas fueled</td>
<td>relatively short lifetime (at present)</td>
</tr>
<tr>
<td>CO₂ emission decreasing</td>
<td></td>
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<tr>
<td>non sound pollutant</td>
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<td>distribution and transmission cost decreasing</td>
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<td>modularity</td>
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Methodology

In this paper the fuel cell power stations are compared with conventional power stations based on the cost of electricity (COE). In the calculation of electricity generating cost, three major costs are involved that include the capital and equipment installation cost, fuel cost and operation and maintenance cost. In order to estimate the capital cost the various parameters including the fuel cell stack, fuel reforming system, electrical system, heat exchanger and heat recovery system costs and other system cost such as air blowers, control sub-systems are defined [6]. The share of capital cost in the cost of electricity is calculated with respect to Equivalent Uniform Annual Cost (EUAC) method. In this method the annual equivalent cost is calculated by Eq. (1).

\[
A = P \frac{i(1+i)^n}{(1+i)^n - 1}
\]

Where A, P, i and n are annual cost, capital cost, rate of return and lifetime respectively. The components of operating and maintenance cost consists of variable O&M cost, fixed repair cost, variable consumable materials cost other than fuel and stack replacement costs. Also, the fuel costs are added to the previous costs.

In this paper COE is calculated for both current and future state of this technology and is compared with the COE of conventional power production technologies. Utilization of the heat also has been taken into account. Also, a sensitivity analysis is done for the variable parameters and the results are presented. The selected parameters for sensitivity analysis are annual operational time, capital cost, O&M cost, lifetime, efficiency and fuel price

Results and Discussion

The subsidized cost of electricity in Iran is 1.66 US cents/kWh. Also, the real cost of electricity is equal to 4.22 US cents/kWh [2]. The input data for calculating the cost of electricity generation with solid oxide fuel cell technology is summarized below:
Based on the above information, the calculated cost of electricity with solid oxide fuel cell technology is as follows:

<table>
<thead>
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<th></th>
<th>current</th>
<th>future</th>
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<tbody>
<tr>
<td>without heat utilization</td>
<td>65.8 c/kWh</td>
<td>6.1 c/kWh</td>
</tr>
<tr>
<td>with heat utilization</td>
<td>65.7 c/kWh</td>
<td>5.7 c/kWh</td>
</tr>
<tr>
<td>conventional technologies</td>
<td>4.22 c/kWh</td>
<td>8.5 c/kWh</td>
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Therefore, the cost of electricity generation by the fuel cell technology is not comparable with conventional technologies. However, one may predict that in near future the cost of fuel cell electricity will be less than other conventional technologies by mass production and reduction of capital cost of fuel cells. The sensitivity analysis is presented in Figs. 1-6

Fig. 1 shows the effect of annual operating time on the cost of electricity. The estimation are based on the predicted future capital cost of 500 US $/kW and O&M cost of 1 US cents/kWh. The future cost of electricity generated by conventional technologies is assumed to be 8.5 US c/kWh. At these conditions, if the fuel cell operates 4800 hours per year, the cost of electricity will be equal to the cost of electricity by conventional technologies.

Fig. 2 presents the effect of capital cost on the cost of electricity. As it is clear the effect of capital cost on the cost of electricity is very significant for low operating time. In fact it is a key factor on the development of fuel cell technology. However, if the fuel cell capital cost doesn't decrease in the future, the fuel cell will not be an alternative technology for power generation.
Fig. 3 Effect of O&M cost on COE

Fig. 3 shows the effect of O&M cost on the cost of electricity. It shows that the O&M cost has a uniform effect on cost of electricity for different operating time. The difference between costs of electricity at high and low O&M cost cases is 2 c/kWh throughout the operational time period.

Fig. 4 Effect of lifetime on COE

Fig. 4 shows that an increase of the fuel cell lifetime will decrease the cost of electricity. However, it has the least effect on the cost of electricity among other variables. Therefore the lifetime is not a key factor in decision making.

Fig. 5 Effect of fuel cell efficiency on COE

Fig. 5 presents the effect of the fuel cell efficiency on the cost of electricity. In fact the increase in fuel cell efficiency has a very significant effect on the electricity cost reduction. Therefore one may conclude that the efforts on development of fuel cell technology should focus on capital the cost reduction and efficiency improvement. Fig. 6 shows that the fuel price, like O&M cost, has a uniform
effect on the cost of electricity at low and high operational times. In fact the cost of fuel is an important factor for countries that import fossil fuel. However, for rich natural gas and oil countries such as Iran it is not a main factor for utilization of fuel cells.

Therefore, the effect of capital cost in the cost of electricity is very significant and it has main role on development of fuel cell technology. If the capital cost doesn't reach to appropriate level, fuel cell technology will not be an alternative technology for power generation at all. The major manufacturing companies’ efforts are focused on this parameter.

Conclusion

- In this paper we have presented a comparison between solid oxide fuel cell power plants and current conventional power plants on the basis of cost of electricity generation.
- The high-temperature fuel cells such as Solid Oxide Fuel Cells show tremendous promise for power generation in near future.
- The results show that current cost of electricity generation from fuel cell technology can not be competitive with conventional technologies. However, as the capital cost has the main role in development of fuel cells, therefore by mass production and advancement of fuel cell technology in the near future the cost of fuel cell electricity will be reduced substantially.
- As Iran has large natural gas resources which can be converted into hydrogen and used in SOFC, therefore, from the economical, environmental and social aspects, the fuel cell technology is a suitable and desirable option for this type of countries

![Fig.6 Effect of fuel price on COE](image)

References


