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Multi Objective Optimization for the Combination of PV, Batt&SOFC

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Abstract

Purpose of this study is optimization of the combination of PV panels, batteries and a solid oxide fuel cell by a multi-objective optimization evolutionary algorithm (PESA). This work compares the use of different fuels for SOFC in the hybrid system. Results are compared to specify better fuel for SOFC from economical and ecological point of view. Optimization is done for two categories of fuel price: international fuel prices and Iran fuel prices. Also the effect of change in power of SOFC is examined to determine enough auxiliary power for this hybrid system. If the angle of panel can change, PV panel productivity increases and required auxiliary power decreases. So, annualized cost and emission are reduced. In this study the effect of monthly change of panel angle is considered.

Keywords: Optimization; SOFC; photovoltaic; hybrid system

Introduction

Providing reliable, environmentally friendly, and affordable energy has been a goal for many countries throughout the world. The rising consumption of energy and falling accessibility of natural resources are increasing the cost of electricity. In addition, as the industry develops, greenhouse gases are becoming a threat to the natural ecosystem. Therefore, renewable energy has received more attention recently. Solar radiation is considered the most preferred renewable energy source. This source of energy in combination with different power systems is used to generate power greatly. BaniasadAskari and Ameri [1] studied a simple optimization method for calculating the optimum configurations of photovoltaic–battery (PV–bat) systems with high reliability and minimum cost. The proposed method had been applied to design a PV–bat system to supply a typical load requirement in a remote region in Kerman-, Iran. Rehman and Al-Hadhrami [2] present a PV-diesel hybrid power system with battery backup for a village being fed with diesel generated electricity to displace part of the diesel by solar. Sadeghi and Ameri [3] presented a multi-objective optimization method for calculating the optimum configurations of photovoltaic–battery systems with high reliability and minimum cost for different tilt angle of panels. Lau et al [4] use the HOMER software to perform the techno-economic feasibility of hybrid PV/diesel energy system. The investigation demonstrated the impact of PV penetration and battery storage on energy production, cost of energy, number of operational hours of diesel generators for a given hybrid configurations .

Fuel cells are electrochemical devices that convert the chemical energy in a fuel into electricity without direct combustion. As a result, they avoid many of the limitations of combustion engines, providing more energetically and exergetically efficient fuel to power conversion. Solid oxide fuel cells are best suited for distributed power generation. SOFCs have relatively high efficiency, low noise (they have not movement components) and little emission. So SOFCs are very suitable to use as an auxiliary system with photovoltaic panels. Wang and Nehrir [5] proposed a stand-alone hybrid alternative energy system consisting of wind, PV, FC, electrolyzer, and battery. Wind and PV are the primary power sources of the system to take full advantage of renewable energy, and the FC–electrolyzer combination is used as a backup and a long-term storage system. A battery bank is also used in the system for short-time backup to supply transient power .

High-temperature operation of SOFCs, typically in the range of 600–1000 °C, effectively activates the processes of reforming and electrochemical oxidation of hydrocarbon fuels in the presence of catalysts. This realization is technically important because it opens the opportunity for SOFCs to use most hydrocarbon fuels, either in the gaseous or liquid state, provided that they are properly cleaned and reformed into simple fuels such as H2 and CO. Cimenti and Hill [6] present an overview of the direct utilization of alternative liquid fuels in solid oxide fuel cells (SOFC) and of the anode material requirements to successfully operate with these fuels. Because of the large number of variables that are usually considered and of the mathematical models applied, classical optimization techniques may consume excessive CPU time or even be unable to take into account all the characteristics associated to the posed problem. During the last 3 decades, heuristic techniques have been applied. One of the most used heuristic techniques has been the multi-objective evolutionary algorithms (MOEAs). Dufo and Bernal [7] applied the strength Pareto evolutionary algorithm to the multi-objective design of isolated hybrid systems, minimizing both the total cost and the unmet load

In this study, a combination of PV-Batt-SOFC is used to generate the needed power for a typical load. A multi-objective optimization performs to optimize the combination when different types of fuel (natural gas, LPG, diesel fuel, kerosene, furnace oil) are used for SOFC. Then results compared with each other to choose the ecological and economical fuel for SOFC. Two categories of fuel price are considered: Iran fuel price and International fuel price. If the angle of panel changes monthly, efficiency of use of sun energy increases and panels produce more power. This work presents the ecological and economical effect of monthly panel angle change. Also the economical and ecological effect of SOFC power change in hybrid system is described.

Modeling of PV panels

The solar energy calculations are made by using the hourly solar radiation data. The electricity power generated by PV systems is directly related to the solar energy received by PV panels, while the PV panels can be placed at different tilt angles and orientations. Most local solar observatories only provide solar irradiance data on a horizontal plane. Thus, an estimate of the total solar radiation incident on any required sloping surfaces is needed. Total solar radiation on an inclined surface is estimated as

$$I_T=I_bR_b+I_dR_d+(I_b+I_d)R_r \quad (1)$$

whereI_b and I_d are direct normal and diffuse solar radiations, R_d and R_r are the tilt factors for the diffuse and reflected part of the solar radiations. Hourly power output from PV system is given by

$$P_{PV} = I_T\eta_m\eta_{pc}P_fA_{PV} (2)$$

whereA_{pv} is the total area of the PV modules in m^2, η_m is the module reference efficiency (0.11), P_f is the packing factor (0.91), and η_{pc} is the power conversion efficiency (0.83). The module reference efficiency η_m can be estimated from the current and voltage of the PV module at maximum power point

$$\eta_m=cu_{mp}V_{mp}/GA_{cs} (3)$$

wherecu_{mp} is the current at maximum power point (A), V_{mp} is the voltage at maximum power point (V), and A_{cs} is the area of a single PV module (m^2). The solar radiation at reference condition G in equation (3) is $1000W/m^2$.

Modeling of the battery system

Battery bank storage is sized to meet the load demand during non-availability period of renewable energy source. At any time t, the charged quantity of the battery bank is subject to the following two constraints:

$$SOC_{min} \leq SOC(t) \leq SOC_{max}, \quad cu_{bat,max}(t) \leq cu_{max} (4)$$

In the above relations, SOC_{min} (30%) and SOC_{max} are the minimum and maximum SOC of the battery, respectively, SOC(t) is the battery SOC at each hour of the year, cu_{max} is the maximum charge current, which is determined as a battery specification by its manufacture. In the present study, the maximum value of the SOC (SOC_{max}) is 1 and 30 per cent is utilized as the value of the SOC_{min} according to the battery specifications (table.1). Depending on the PV and wind energy production and the load power requirements, the state of charge of battery can be calculated from the following equations:

Battery charging,

$$SOC(t+1)=SOC(t)\times[1-\sigma(t)]+\frac{cu_{bat}(t)\times\Delta t\times\eta_{ch}(t)}{C_{bat}} (5)$$

Battery discharging,

$$SOC(t+1)=SOC(t)\times[1-\sigma(t)]-\frac{cu_{bat}(t)\times\Delta t\times\eta_{dch}(t)}{C_{bat}} \quad (6)$$

where σ(t) is the hourly self-discharge rate, which 0.018 percent is used in this study. η_{ch} and η_{dch} are the charge and discharge efficiency of the battery, respectively.

Solid oxide fuel cell

Solid oxide fuel cells (SOFCs) offer a clean, low-pollution technology to electrochemically generate electricity at high efficiencies; since their efficiencies are not limited by the Carnot cycle of a heat engine. These fuel cells provide many advantages over traditional energy conversion systems including high efficiency, reliability, modularity, fuel adaptability, and very low levels of NOx and SOx emissions. Quiet, vibration-free operation of SOFCs also eliminates noise usually associated with conventional power generation systems.

The high operating temperature (700-1000°C) of solid oxide fuel cells (SOFCs) has a number of consequences, the most important of which is the possibility of running the cells directly on practical hydrocarbon fuels without the need for a complex and expensive external fuel reformer that **is** necessary for low-temperature fuel cells. Low-temperature proton exchange membrane (PEM) fuel cells are poisoned by even a small quantity of carbon monoxide and require very pure hydrogen as the fuel, therefore placing significant demands, and hence cost, on a complex external fuel processor. By contrast, in an SOFC, the hydrocarbon fuel is catalytically converted (internally reformed), generally to hydrogen and carbon monoxide (synthesis gas) together with some carbon dioxide, within the cell stack, and the carbon monoxide and hydrogen are then electrochemically oxidized to carbon dioxide and water at the anode, with production of electrical power and high-grade heat.

Another key advantage of SOFCs over other types of fuel cells is the flexibility in the choice of fuel, which derives from the elevated operating temperature and the tolerance to carbon monoxide, and to some extent, other impurities in the fuel. So a great range of fuel such as natural gas, LPG,ethanol, diesel fuel, kerosene, furnace oil and etc. can be used in SOFCs.

Cost

In finance, theannualized cost (ANC) is the cost per year of owning and operating an asset over its entire lifespan. In the present study, to compare different configurations of economical aspects, annualized cost is used. In order to calculate ANC, annualized initial capital cost, annualized replacement cost, and annualized operating and maintenance cost will be added.

Annualized initial capital cost:$C_{acap}=C_{cap}.CRF(i,R_{proj})(7)$

C_{acap}, C_{cap}, CRF, i, R_{proj} are annualized initial capital cost, initial capital cost, capital recovery factor, real interest rate, and system lifespan respectively.

Annualized replacement cost: $C_{arep}=C_{rep}.f_{rep}.SFF(i,R_{comp})-S.SFF(i,R_{proj})$(8)

C_{arep}, C_{rep}, f_{rep}, SFF, R_{comp}, S are annualized replacement cost, replacement cost, ratio of capital recovery factor, sinking fund factor, and lifespan of component and salvage value, respectively.

Operating and maintenance costs are usually annualized.

Annualized cost: $\mathrm{ANC} = \mathrm{C_{acap}} + \mathrm{C_{arep}} + \mathrm{C_{a\,O\&M}}(9)$

Fuel prices in Iran and other placesare different. In the present study, comparison is done based on two fuel prices:

1. Iran fuel price
2. International fuel price

Table (1) shows the price of fuel. In Iran fuel price is multi-rate so the mean fuel prices were used. Table (2) shows the initial, replacement, operation and maintenance cost of different components. This table also shows life span and power of the components.

At higher sulfur concentrations, irreversible sulfidation of the catalyst or anode of SOFC can occur, so sulfur must be removed by various methods. The low-sulfur kerosene (k-1 kerosene) price is about 30% higher than the higher sulfur kerosene (k-2 kerosene) price. So in this study, the cost of liquid fuels (diesel fuel, kerosene, furnace oil) increases about 30% in order to consider the desulfurisation cost.

Table1. Different fuel prices

	Iran fuel price	International fuel price
NG	0.171(\$/m$^{3)}$	0.167(\$/m$^{3)}$
LPG	0.146(\$/kg)	2.11(\$/kg)
Kerosene	0.0815(\$/lit)	1.05(\$/lit)
Furnace Oil	0.163(\$/lit)	1.16(\$/lit)
Diesel Fuel	0.285(\$/lit)	1.056(\$/lit)
Ethanol	1.06(\$/lit)	0.858(\$/lit)

Table 2. Specifications of different components

	Power	Initial capital cost (\$/KW)	Replacement cost (\$/KW)	O&M cost per year (\$/KW)	Life span (years)
PV panel	200 W	1000-3000	0	0.0025	25
Battery	3000 Ah	100	90	0.005	15
Inverter	10 KW	200-400	180-360	0.0015	15
SOFC	140 KW	3000	2700	0.0086	15

Fuel consumption

The specific fuel consumption is defined as the fuel consumption required to produce 1 kWh of energy and it is equal to the hourly fuel consumption for supplying a given load during 1 h. According to Skarstein and Uhlen [8], the hourly fuel consumption can be approximated as follows:

$F.C.=A\times P(t)+B\times P_n$(10)

Where A and B are constants (B approximately equals to zero for SOFC), P(t) is the power generated at t moment and P_n is the rated nominal power. Table (3) shows A constant for different fuels.

Table 3. A constant for different fuels

	NG	LPG	Ethanol	Kerosene	Furnace Oil	Diesel Price
A constant	0.18154 (m^3.kw/h)	0.1321 (kg.kw/h)	0.289 (lit.kw/h)	0.1706 (lit.kw/h)	0.1477 (lit.kw/h)	0.1684 (lit.kw/h)

Calculation of constant of A

Bloom Energy's ES-5400 solid oxide fuel cell produces 100 KW AC base load. This SOFC model uses natural gas as fuel and has 52% electrical efficiency (relative to the LHV). ES-5400 model consumes 18.154 m^3/h and so, constant of A for NG as fuel is 0.18154. Now, according to the given NG consumption, other fuels consumption is calculated.

NG contains about 80-98% of CH_4. So, in this study CH_4 gives as NG. In ideal situation, by steam reforming of one mole CH_4 (Equation 10), four moles H_2 and CO are produced.

$$CH_4 + H_2O \rightarrow CO + 3H_2(11)$$

When an external load is applied to the cell, oxygen is reduced at the porous air electrode to produce oxide ions. These ions migrate through the solid electrolyte to the fuel electrode, and they react with the fuel, H_2 or CO, to produce H_2O or CO_2, and it is obvious, from number of released electron, H_2 and CO reactions are similar.

Equation 11 shows the steam reforming of kerosene ($C_{12}H_{26}$):

$$\mathrm{C_{12}H_{26}+12H_2O\rightarrow 12CO+25H_2}(12)$$

So, each kerosene mole produces 37 moles H_2 and CO. This means, each kerosene mole acts like 9.25 moles CH_4. 1kmole CH_4 is approximately 24.4 m^3 CH_4 and 1kmole kerosene is approximately 213 liters. So, 1m^3 of NG consumption in SOFC is equivalent to 0.94 lit of kerosene consumption and constant of A for kerosene is 0.17064. This method is used to obtain constant of A for other fuels.

LPG includes both propane and butane. In different places of the world and in different time of the year, the combination of the LPG is changed. In this work, the combination of 70% butane and 30% propane is considered for Iran LPG and the combination of 10% butane and 90% propane is considered for international LPG. The difference of constant of A between these two types of LPG is very low, and it takes about 0.1321.

Reliability

Reliability of the system is expressed in terms of loss of power supply percent (LPSP). The objective function, LPSP, can be described by:

$$\mathrm{LPSP}=\frac{\sum_{t=1}^{N_h}\mathrm{hours}[CU_{supply}(t)<Cu_{needed}(t)]}{N_h}\times 100 \qquad (13)$$

In the above relation, N_h is the number of time intervals (8760, number of hours in a year) and $I_{needed}(t)$ is the current needed by the load, which can be expressed as:

$$Cu_{needed}(t)=\frac{p_{load}(t)-P_{PV}(t)}{V_{bat}}\times\eta_{batt}(14)$$

$$Cu_{supply}(t)=\min\left(\frac{0.2\times C_{bat}}{\Delta t},\frac{C_{bat\times(SOC(t)\times(1-\sigma(t))-SOC_{min})}}{\Delta t}\right)(15)$$

$Cu_{needed}(t)$ is the current required for the load at hour t and $Cu_{supply}(t)$ is the current supplied by the system at hour t. η_{batt} is considered 0.86. $P_{load}(t)$ is the electrical load power requirements at hour t and $P_{PV}(t)$ is the power generated by PV modules at hour t.

Pollution emission

Table (4) shows CO2 emission of unit fuel consumption for different fuels. The hours of SOFC operation and therefore fuel consumptions are specified, so by product the fuel consumption to emission of unit fuel consumption, total emission will be determined.

Table 4. CO2 emission per unit fuel consumption for different fuels

	CO2 emission
NG	2.2 (kg/m^3 NG)
LPG	3.026 (kg/kg LPG)
Kerosene	2.478 (kg/lit Kerosene)
Furnace Oil	2.92 (kg/lit Furnace Oil)
Diesel Fuel	2.626 (kg/lit Diesel Fuel)
Ethanol	1.509 (kg/lit Ethanol)

Multi-objective optimization evolutionary algorithm

The implemented multi-objective algorithm is based on PESA because it has approximately fast convergence, probably due to its higher elitism intensity and it also has good accuracy. PESA has two parameters concerning population size i.e PI (the size of the internal population IP) and PE (the maximum size of the archive or external population). It has one parameter concerning the hyper-grid crowding strategy. The main steps in this algorithm are (i) Generate and evaluate each of an initial internal population (IP) of PI chromosomes and initialize the external population (EP) to the empty set.(ii) Incorporate the non-dominated members of IP into EP.(iii) If a termination criterion has reached then stop, returning the set of chromosomes in EP as the result. Otherwise, delete the current contents of IP and repeat the following until PI new candidate solutions have been generated. With probability P_c, select two parameters from EP. Produce a single child via uniform crossover and mutate the child via bit-flip mutation. With probability $(1-P_c)$ select one parent and mutate it to produce a child.(iv) Repetition of the same process.

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1. Generate and evaluate each of an initial internal population (IP) of PI chromosomes.
2. Initialize the external population (EP) as empty set.
3. For t=1 to Number of Generations
3.1. Incorporate the non-dominated members of IP into EP.
3.2. Delete the current content of IP.
3.3. Until obtaining new solution of PI.
3.3.1. Select two parents from EP with probability $P_c$
3.3.2. Recombine this two parents for obtaining one offspring
3.3.3. Mutate the offspring
3.3.4. Select one parent from IP with probability $(1-P_c)$
3.3.5. Mutate the parent to produce one offspring
3.3.6. Add the two obtained offspring into IP
4. Return to 3
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This algorithm is in charge of finding the designs that manage to, simultaneously, minimize the ANC of the system, the pollutant emissions, and the LPSP. It has been developed using the MATLAB programming language. The algorithm (MOEA) can search for the configuration of PV panels, batteries, auxiliary system, and inverter which minimizes the three objectives mentioned.

Result

This study presents a multi-objective optimization for photovoltaic panels-batteries-solid oxide fuel cell hybrid power generation system. This optimization performs when different types of fuel (NG, Ethanol, LPG, Diesel Fuel, Furnace Oil, Kerosene) are used for SOFC. Then results compared with each other from ecological and economical point of view to specify the best fuel for use in SOFC. Because fuel prices in Iran and other placesare different, comparison is done based on two fuel prices: Iran fuel price and International fuel price. It is assumed that there are about 4000 m^2 space for PV panels and other equipment. Every 200 W photovoltaic panel occupies about 1.5 m^2. And if it is considered that SOFC, batteries, inverters and fuel tanks occupy about 200 m^2, up to 2530 panels can be arranged. So the number of PV panel range of change is from 0 to 2530.The measured annual average electric energy consumption of 500 typical households is considered.

Given the discontinuous nature of solar energy, the use of auxiliary power generator is essential. Select the appropriate power for auxiliary system is important. Exorbitance power can increase emission and annualized cost, and insufficient power can reduce reliability of the hybrid system. In this work, LPSP=1% is considered as a desirable LPSP. This means that for 87.6 hours of the year and about 14.4 minutes of the day, the needed load cannot be supplied.

If the panelangle can change, PV panel productivity increases and auxiliary power can decreases. So, annualized cost and emission are reduced by change of panel angle. In this study the effect of monthly change of panel angle is considered.

Fig. 1 shows the Pareto frontiers for hybrid system in ANC-LPSP coordinates for different cases. In all cases, maximum number of panels is 2530. It is observed when the angle of panel (30˚) is constant, the best choice for power of auxiliary power system to obtain LPSP=1% is 120 kw. If power of auxiliary power system increases to 200 kw, the ANC of hybrid system increases uselessly, and if power of auxiliary power system decreases to 50 kw, hybrid system cannot reach to LPSP=1%. This figure show, if the angle of panel changes monthly, hybrid system with 50 kw auxiliary system can reach to LPSP=1% and also, annualized cost of hybrid system reduces.

Fig. 2 shows the use of a system with lower power level reduces CO2 emission. therefore, from ecological point of view, 50 kw power system is better, but with fix panel angle, the hybrid system cannot reach to LPSP=1%. If the panel angle change monthly, as figure shows, hybrid system with 50 kw auxiliary system can supply the needed reliability and also the best ecological conditions.

Figs. 1 and 2 show the Pareto frontiers for the hybrid system when SOFC uses diesel fuel as fuel. To show the effect of fuel type and priceon appropriate power selection, figs. 3 show Pareto frontiers for the hybrid system when SOFC uses NG as fuel. It is obvious that the fuel type and pricedo not have any effect on appropriate power selection. So the best power for auxiliary system is 120 kw when the panel angle is fix, and is 50 kw when the angle of panel is changed.

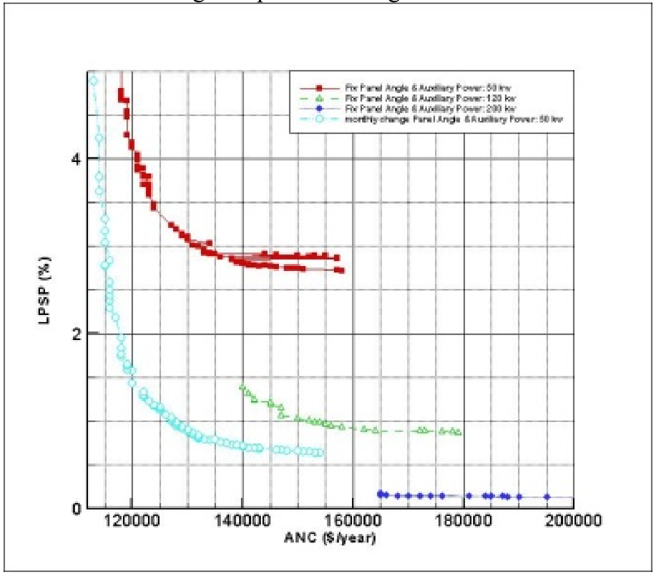

Figure 1.Pareto frontier of hybrid system with different power of SOFC, LPSP to ANC, International fuel price, Diesel as Fuel.

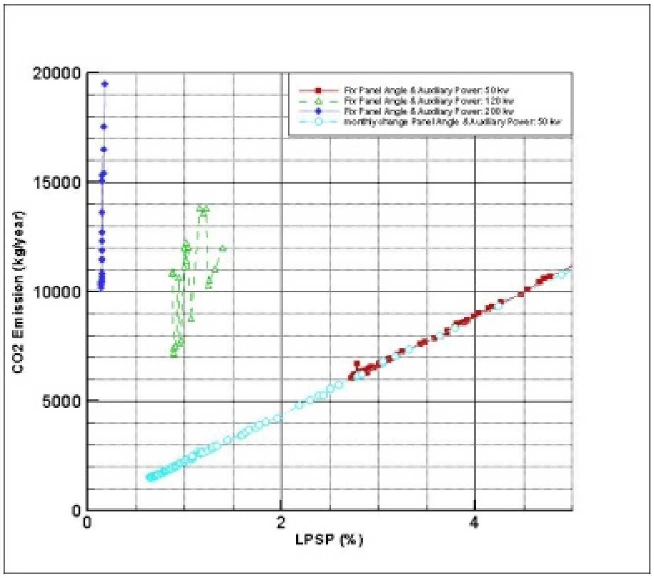

Figure 2.Pareto frontier of hybrid system with different power of SOFC, CO2 emission to LPSP, International fuel price, Diesel as Fuel.

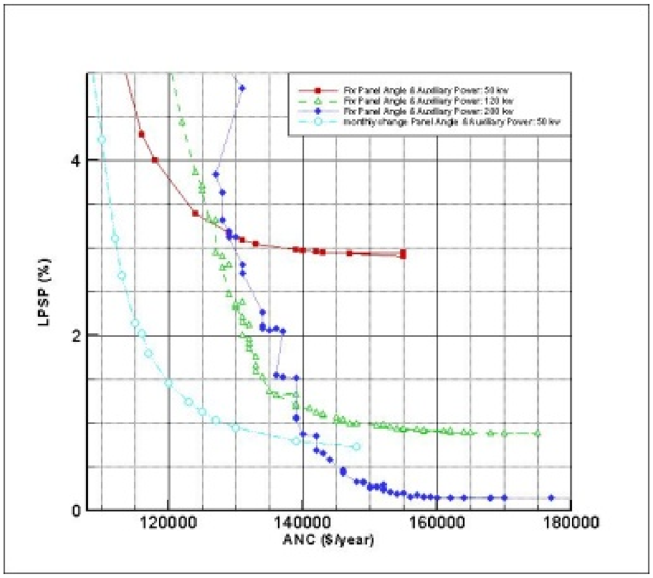

Figure 3. Pareto frontier of hybrid system with different power of SOFC, LPSP to ANC, International fuel price, NG as Fuel .

Fig. 4 shows Pareto frontiers in LPSP-ANC coordinates for hybrid system when SOFC use different fuels. These frontiers are for international fuel price and fix panel angle. It is obvious that the use of NG as fuel in SOFC cause the least annualized cost of the hybrid system. Other fuels cause approximately the same ANC. So, if there is not NG pipeline in a place, other fuels can be used. Ethanol is a renewable fuel that can be produced through sugarcane and corn farms' wastes. As a result ethanol can be a good alternative in limited fossil fuels situation. LPG (liquefied petroleum gas) is in high pressure and transport in special cylinders, but other fuels are naturally liquid and their transportation is easy. Fig. 5 shows CO2 emission of the hybrid system when SOFC use different fuels. It shows, that the LPG fuel cause the least CO2 emission. Pareto frontiers in this figure are fluctuating. The reason depends on number of batteries. All of the possible number of panels is used in this range of LPSP and the operation of auxiliary system depends on the changes of the number of batteries. It means that the auxiliary system operation decreases when the number of batteries increase. As a result, CO2 emission reduces but annualized cost increases. Visa versa, if the number of batteries decreases, the auxiliary system operation and CO2 emission increases but annualized cost decreases. Therfore, some solutions will have lower cost and others will have lower CO2 emission. This causes the fluctuations in Pareto frontiers.

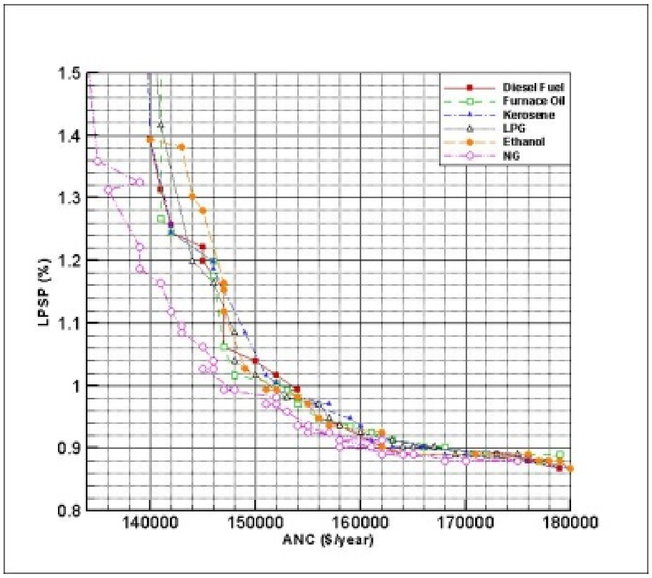

Figure 4.Pareto frontier of hybrid system with different fuels for SOFC, LPSP to ANC, International fuel price, Fix Panel Angle.

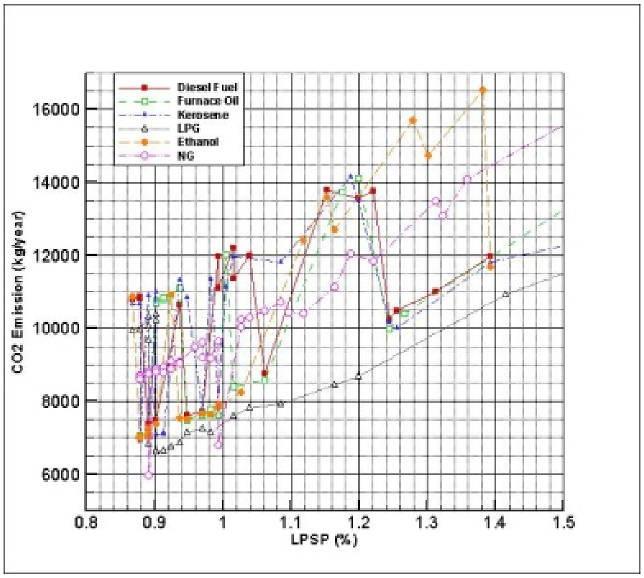

Figure 5.Pareto frontier of hybrid system with different fuels for SOFC, CO2 emission to LPSP, International fuel price, Fix Panel Angle.

Fig. 6 shows Pareto frontiers in LPSP-ANC coordinates for different fuels with Iran fuel price and fix panel angle. In this situation, LPG and kerosene causes lower ANC, and diesel fuel and ethanol causes higher ANC. But in low LPSP, there is not much difference, and different fuels cause approximately same ANC. Fig. 7 shows Pareto frontiers in CO2-LPSP coordinates for different fuels with Iran price. Using NG and ethanol causes approximately lower CO2 emission. In this figure, due to previously-mentioned reasons, Pareto frontiers fluctuate again.

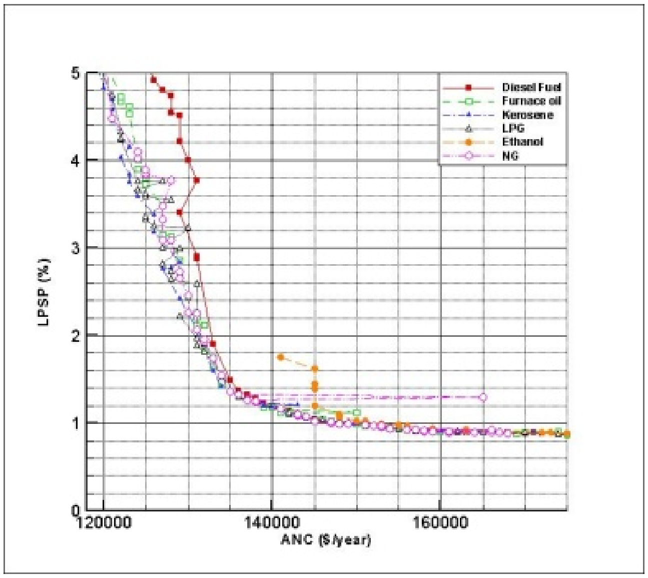

Figure 6.Pareto frontier of hybrid system with different fuels for SOFC, LPSP to ANC, Iran fuel price, Fix Panel Angle.

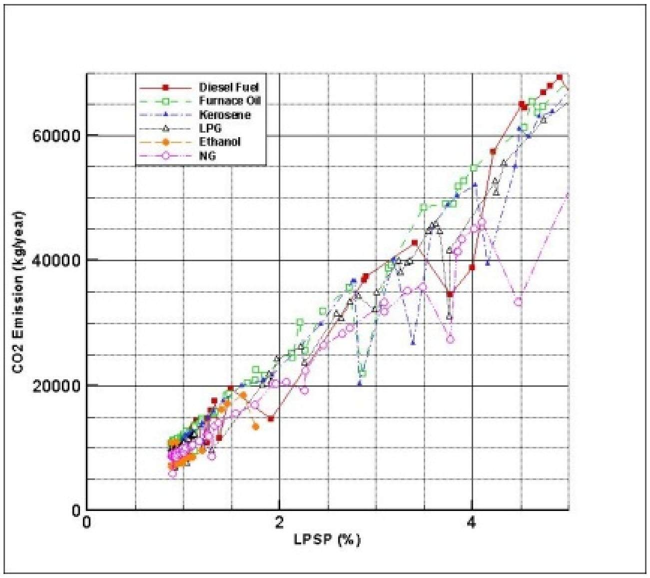

Figure 7.Pareto frontier of hybrid system with different fuels for SOFC, CO2 emission to LPSP, Iran fuel price, Fix Panel Angle.

After that, Pareto frontiers for different fuels are considered when the panel angle changes monthly. Fig. 8 shows Pareto frontiers in LPSP-ANC coordinates for international fuel prices. It is obvious that NG causes the least ANC again, but because of lower auxiliary power (50 kw) in this situation, the difference in ANC is less significant. In LPSP=1%, the ANC of different fuel are approximately equal. Fig. 9 shows Pareto frontiers in CO2-LPSP coordinates. NG and LPG emit lower CO2. Other fuels especially diesel fuel emit higher amount of

CO2. Because of lower auxiliary power and lower auxiliary system operation, the Pareto frontiers' fluctuation is very low.

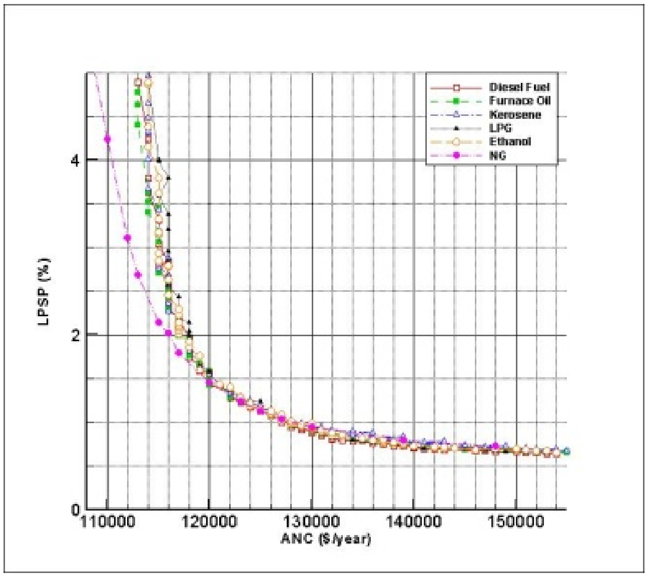

Figure 8.Pareto frontier of hybrid system with different fuels for SOFC, LPSP to ANC, International fuel price, Monthly Change Panel Angle.

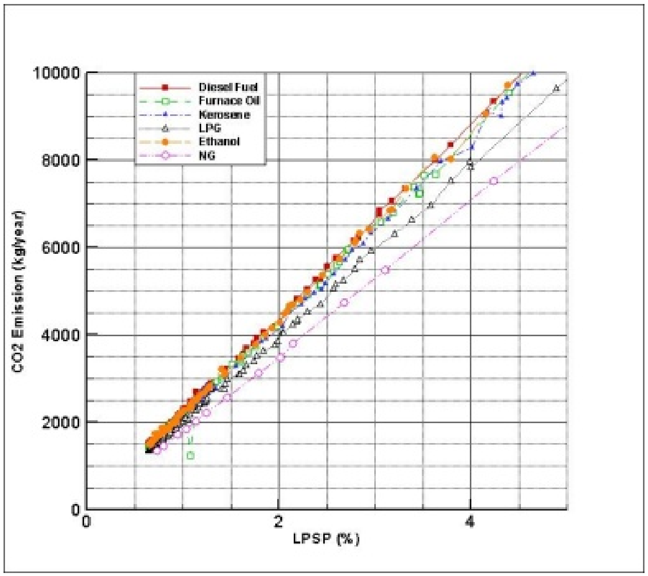

Figure 9.Pareto frontier of hybrid system with different fuels for SOFC, CO2 emission to LPSP, International fuel price, Monthly Change Panel Angle.

Conclusion

According to the results, the most appropriate fuel for SOFC in the hybrid system is natural gas. It causes low ANC and low CO2 emission. NG needs pipeline for transportation; therefore, where there is no NG pipeline, the best fuel to be used in SOFC is LPG. Although CO2 emission per kg LPG is relatively high, because of low constant of A, LPG costs little and produces low CO_2 emission. LPG must be transported under pressure in special cylinders. Therefore, if the suitable conditions for using LPG are not provided, the next best choice is furnace oil for international category and kerosene for Iran category. Ethanol is a renewable fuel, And so for limited fossil fuels situation, ethanol can be a good alternative. Moreover, sulfur compounds in NG, LPG and ethanol are much less than these in other fuels, so there is no need for additional equipment to desulfurization. If the panel angle changes monthly, efficiency of use of solar energy increases and panels produce more power. Consequently, the required auxiliary power is decreased and hybrid system gives better economical and ecological conditions.

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Multi Objective Optimization for the Combination of PV, Batt&SOFC

Abstract

Purpose of this study is optimization of the combination of PV panels, batteries and a solid oxide fuel cell by a multi-objective optimization evolutionary algorithm (PESA). This work compares the use of different fuels for SOFC in the hybrid system. Results are compared to specify better fuel for SOFC from economical and ecological point of view. Optimization is done for two categories of fuel price: international fuel prices and Iran fuel prices. Also the effect of change in power of SOFC is examined to determine enough auxiliary power for this hybrid system. If the angle of panel can change, PV panel productivity increases and required auxiliary power decreases. So, annualized cost and emission are reduced. In this study the effect of monthly change of panel angle is considered.

Keywords: Optimization; SOFC; photovoltaic; hybrid system