Environmental Protection through Pollution Reduction of CO2, SOx, NOx and Other Emissions by Optimal Location of Fuel Cell using Genetic Algorithm (GA) and Comparison with Particle Swarm Optimization (PSO)

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Abstract

Utilization of fossil plants for power generation could be lead to some disadvantages. One of this is pollution of the usual combustion which products (SOx, particulates, CO, and various unburned or partially burned hydrocarbons) are not emitted, although there may be some thermal NOx when fuel cells operate at high temperatures. Renewable energy as a suit alternative could be used instead of fossil plants in distribution system to support load demand at distribution side. Therefore this paper focuses on the fuel cell placement to help the emission reduction. The objective function that considered in this research is emission reduction and it is minimized using two intelligent methods and finally the results of these two methods are compared. Genetic algorithm (GA) and Particle swarm optimization (PSO) are implemented and results are analyzed and the best method from point of view fast convergence and mimin iteration needed for convergence is selected.

INTRODUCTION

Energy use also causes serious threats to global security. Natural resources (energy being one of them) have been an important factor in many conflicts during the 20th century [1]. The main oil reserves are located in a handful of countries, and about 70% of the known oil reserves are located in countries in the Middle East [2]. Promoting the stability of these countries has therefore been an important part of the strategic policies of the main world political powers [3]. Another threat to global security is the link between nuclear power and the risk of nuclear weapons proliferation [1, 3]. Nuclear power, currently producing about 15% of global electricity, was expected during the 1970s and 1980s to be rapidly expanded. Such an expansion would not only increase the risk of proliferation as more nations would gain access to materials suitable for nuclear weapon manufacture, but would probably also necessitate the introduction of plutonium breeder reactors and other systems requiring the processing, separation, and recycling of materials suitable for use in nuclear weapons [4].

During recent decades, the environmental impact of energy use has been a major area of discussion and research. Although many policies have been implemented to reduce this impact, energy use is still a dominating contributor to many local, regional and global environmental problems, especially those connected with air pollution.

Energy use in the transportation sector plays a particularly important role as emissions at street level pose a considerable health risk. Furthermore, the emissions of nitrogen oxides (NOx), volatile organic compounds (VOC) and carbon monoxide (CO) from the transportation sector are high per unit energy used, compared with the emissions from heat and electricity production plants.

Many alternative solutions could be used for this goal (decreasing the cost). Using renewable energy system is one of the possible solutions. A growing interest in renewable energy resources has been observed for several years, due to their pollution free energy, availability, and continuity. In practice, use of hybrid energy systems can be a viable way to achieve trade-off solutions in terms of costs. Photovoltaic (PV) and wind generation (WG) units are the most promising technologies for supplying load in remote and rural regions [5].

Some researches have analysis the usage of fuel cell for this purpose. A hybrid system including wind turbines (WT) and fuel cell (FC) is studied in [6], to examine the efficiency of wind power. Electrolyzers and hydrogen tanks have been used to store the excess power available from WTs when WTs’ power is more than...
the load demand; and the stored energy is used when a power deficit from WT's occurs. The only control variable of the problem is the WT size and other equipment sizes (Electrolyzer, FC, Hydrogen storage tank) are dependent on it.

1. Fuel Cells versus conventional combustion - advantages
Fuel cells convert chemical energy contained in a fuel (hydrogen, natural gas, methanol, gasoline, etc.) directly into electrical power. As shown in Fig.1 by avoiding the intermediate step of converting fuel energy first into heat, which is then used to create mechanical motion and finally electrical power, fuel cell efficiency is not constrained by the Carnot limits of heat engines [7].

![Fig. 1: Conversion of chemical energy to electricity and fuel cell.](image1)

Fuel-to-electric power efficiencies as high as 65% are likely, which gives fuel cells the potential to be roughly twice as efficient as the average central power station operating today. Fuel cells have other properties besides high efficiency that make them especially appealing. The usual combustion products (SOx, particulates, CO, and various unburned or partially burned hydrocarbons) are not emitted, although there may be some thermal NOx when fuel cells operate at high temperatures.

They are vibration-free and almost silent, which, when coupled with their lack of emissions, means they can be located very close to their loads-for example, in the basement of a building. Being close to their loads, they not only avoid transmission and distribution system losses, but their waste heat can be used to cogenerate electricity and useful heat for applications such as space heating, air-conditioning, and hot water. Fuel cell cogeneration systems can have overall efficiencies from fuel to electricity and heat of over 80%. High overall efficiency not only saves fuel but also, if that fuel is a hydrocarbon such as natural gas, emissions of the principal greenhouse gas, CO2, are reduced as well. In fact, as shown in Fig.2 if fuel cells are powered by hydrogen obtained by electrolysis of water using renewable energy sources such as wind, hydroelectric, or photovoltaic, they have no greenhouse gas emissions at all [8].

![Fig. 2: Powered fuel cells by hydrogen which obtained by electrolysis of water using renewable energy sources.](image2)

Fuel cells are easily modulated to track short-term changes in electrical demand, and they do so with modest compromises in efficiency. Finally, they are inherently modular in nature, so that small amounts of
generation capacity can be added as loads grow rather than the conventional approach of building large, central power stations in anticipation of load growth.

Fuel cells show great promise to be an important DG source of the future due to their many advantages, such as high efficiency, zero or low emission and flexible modular structure. Combining FCs with energy storage systems like batteries and supercapacitors makes the hybrid distributed generation systems (HDGS) to operate properly under dynamic conditions [9]. The FC power generation is considered as shown in Fig.3. [10].

![Fig. 3: Fuel-power curve of fuel cell.](image)

The cost-size characterization of FC is shown in Figs.4.

![Fig. 4: Cost-size characterization of fuel cell.](image)

2. **Intelligent based optimization approach:**

2.1 **GA:**

Genetic Algorithm is a general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time [11]. There are usually three operators in a typical genetic algorithm [12]: the first is the production operator (elitism) which makes one or more copies of any individual that posses a high fitness value; otherwise, the individual is eliminated from the solution pool; the second operator is the recombination (also known as the 'crossover') operator. This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the right hand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. Thus, the probability of a better offspring is greatly enhanced; the third operator is the 'mutation' operator. This operator acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings. Since frequent application of this operator would lead to a completely random search, a very low probability is usually assigned to its activation.
2.2 PSO:
In a PSO system, Birds’ (particles) flocking optimizes a certain objective function. Each particle knows its current optimal position ($p_{best}$), which is an analogy of personal experiences of each particle. Each particle also knows the current global optimal position ($g_{best}$) among all particles in the population [13]. PSO can have several solutions at the same time, and particles have a cooperative relationship for sharing messages. Through specific equations, each particle adjusts its position and determines the search direction according to its search memory and those of others. In other words, it tries to reach compatibility between local search and global search. The search memory of a particle is the objective function and the optimum position found by the particle.

3. Economic Formulation:
3.1 Cost-Benefit Analysis:
To better techno-economic analysis of renewable energy resources implementation in distribution system, the costs and benefits of RES allocation in the network can be expressed as follows [14-15], with the cash flows presented below in Fig.5.

At first the general cost involved with FC optimization is presented.
- **The investment cost of FC units:**
  \[
  C_1 = \sum_{i=1}^{m} \text{Fix}_i
  \]
  Where, Fix is the investment cost of FC installed.
- **Maintenance cost:**
  \[
  C_2 = \sum_{i=1}^{m} \text{CM}_i
  \]
  CM is the maintenance cost per year.
- **The Profit of Emission Reduction:**
  The main profit of FC installation is the profit of CO2 sold which encourages engineering planers to employ the FCs in distribution systems.
  The profit of CO2 sold,
  \[
  C_3 = 8760 \times \text{CF} \times \sum_{i=1}^{m} \text{Pi} \times \Phi \times \text{Cost}_c
  \]
  Where, m is the number of FCs installed, Pi is the rated real power output of FCs (kW), \( \Phi \) is the Carbon exhaust coefficient (0.612 kg CO2 e/kWh) [16], Costc is the carbon trading price (NT$/ton) and CF is the capacity factor of FCs.

3.2 Economical relations:
In this study, the main economical relations, employed are illustrated in detail below:
- **Annualized Cost:**
It is determined by multiplying the initial cost by the capital recovery factor (CRF) and illustrated as below [17]:

\[ C_{\text{ann,tot}} = C_{\text{int}} \times CRF(i, R_{\text{proj}}) \]  

(4)

where, \( CRF \) is determined as follows [18]:

\[ CRF(i, R_{\text{proj}}) = \frac{i(1+i)^{R_{\text{proj}}}}{(1+i)^{R_{\text{proj}}}-1} \]  

(5)

Where, \( R_{\text{proj}} \) indicate the project lifetime and \( i \) represents the annual interest rate and is related to nominal interest rate and inflation rate as bellow [18]:

\[ i = \frac{i^* - f}{i^* + f} \]  

(6)

Following equation gives the annualized cost versus of future worth:

\[ C_{\text{ann,tot}} = FW \times SSF(i, R_{\text{proj}}) \]  

(7)

where, \( SSF \) represents sinking fund factor and determined as follows [19]:

\[ SSF(i, R_{\text{proj}}) = \frac{i}{(1+i)^{R_{\text{proj}}}-1} \]  

(8)

- **Replacement Cost Duration:**
  Following equation gives the salvage value of each component of market at the end of the project lifetime [19].

\[ R_{\text{rep}} = R_{\text{comp}} \times INT\left(\frac{R_{\text{proj}}}{R_{\text{comp}}}\right) \]  

(9)

where, \( R_{\text{comp}} \) represents the component-lifetime.

- **Remaining Life of the Component**
  It is determined as follows,

\[ R_{\text{rem}} = R_{\text{comp}} - (R_{\text{proj}} - R_{\text{rep}}) \]  

(10)

- **Annualized Replacement Cost:**
  This parameter is expressed by the following equation [20-21]:

\[ C_{\text{arep}} = C_{\text{rep}} \times SSF(i, R_{\text{comp}}) - (\frac{R_{\text{rem}}}{R_{\text{comp}}}) \times SSF(i, R_{\text{proj}}) \]  

(11)

Where, \( C_{\text{rep}} \) indicate the replacement cost for components of system in end of its lifetime and \( f_{\text{rep}} \) is a factor due to difference between the component and the project lifetime. It is formulated as follows [20-21]:

\[ f_{\text{rep}} = \begin{cases} 
    \frac{CRF(i, R_{\text{proj}})}{CRF(i, f_{\text{rep}})}; & R_{\text{rep}} > 0 \\
    0; & R_{\text{rep}} < 0 
\end{cases} \]  

(12)

4. **Simulation and results:**

In order to investigate the effect of optimal location of fuel cell on emission reduction, as indicated further an objective function based cost of investment, operation and benefit incoming due to pollution reduction id considered and finally y it optimized using genetic algorithm and particle warm optimization approaches.

To analyze the performance of two intelligent method, the optimal placement of fuel cell with aim of emission reduction with considering economical aspects, a standard 33-bus test system as shown in Fig.6 is considered and the results of optimization on this system is evaluated.
Fig. 6: standard 33-bus test system.

The results of simulation versus optimal cost ($), iterations numbers and computational time are listed in Table 1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Optimal Cost ($)</th>
<th>Iterations</th>
<th>Computational Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA</td>
<td>128911</td>
<td>350</td>
<td>845</td>
</tr>
<tr>
<td>PSO</td>
<td>125216</td>
<td>380</td>
<td>735</td>
</tr>
</tbody>
</table>

At first, in order to select a suitable searching method, a system with 33 buses has been considered and fuel cell optimal location panning using two intelligent methods including GA, PSO is analyzed. The simulation results of this analysis showed the significant computational time reduction and faster convergence of PSO in comparison with GA and.

Therefore in large scale radial system and real system, the proposed method is solved using PSO. The computational time using GA is approximately 800 [ms] and using PSO it is 700 [ms]. The time is system dependent, in our case Intel Core 2 duo, T5800 @ 2 GHz. The convergence of the solutions to optimal cost is shown in Fig. 7.

Fig. 7: the convergence of the solutions of GA and PSO to optimal cost.

The optimal location of fuel cells is presented in Table 2.

<table>
<thead>
<tr>
<th>Method</th>
<th>Optimal Location</th>
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<tbody>
<tr>
<td>ABC</td>
<td>3,5,8,12,17,23,26,28</td>
</tr>
<tr>
<td>BFO</td>
<td>3,5,12,17,23,26,28</td>
</tr>
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One of the conventional methods of solving this problem is lambda-iteration method but owing to tedious calculations and its inability to solve multi-modal and discontinuous problems, novel techniques have replaced it. The optimal cost of small scale problem was found out to be 123185 $ using lambda iteration method, while as shown in table 6 the optimal cost is calculated as 128911$ and 125216$ using GA and PSO respectively.

As listed in table 1, the PSO result for optimize the total cost is closer to result of lambda iteration method. As shown in table 1, a total of 350 and 380 iterations respectively were required to converge to the optimal solution for the problem using GA and PSO.

Conclusion:
This research focuses on the environmental protection by avoiding of CO₂ emissions using fuel cell (FC) placement in demand side of power distribution system.

This paper deals with optimal location of fuel cell in distribution system. In this research two intelligent methods including Genetic Algorithm (GA) and Particle Swarm, Optimization (PSO) are used to optimize the best location of fuel cell. Finally results of these optimizations from point of view computational time and speed convergence are compared and analyzed.

REFERENCES