

## OPEM : Open Source PEM Cell Simulation Tool

Sepand Haghighi<sup>1</sup>, Kasra Askari<sup>2</sup>, Sarmin Hamidi<sup>3</sup>, and Mohammad Mahdi Rahimi<sup>4</sup>

<sup>1</sup> Sharif University of Technology <sup>2</sup> Isfahan University of Technology <sup>3</sup> University of Tehran <sup>4</sup> Amirkabir University of Technology

DOI: [10.21105/joss.00676](https://doi.org/10.21105/joss.00676)

### Software

- [Review](#) ↗
- [Repository](#) ↗
- [Archive](#) ↗

Submitted: 11 April 2018

Published: 20 July 2018

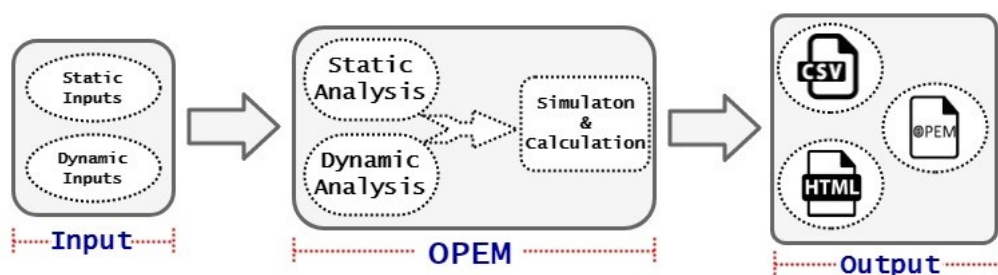
### License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC-BY](#)).

### Summary

The sun and wind as renewable energy sources are attracting more regard as alternative energy sources. In addition to the decreasing fuel sources, pollution and global warming are important problems. Fuel cells are a beneficial energy technology that generates electric energy through the reaction between the fuel sources rich in hydrogen and oxygen. In comparison with combustion engines, fuel cells have many advantages, such as high efficiency and low emissions. Furthermore the by-products of fuel cells are heat and water. Proton exchange membrane fuel cells (PEMFCs) have attracted much interests recently. PEM fuel cells are Pollution-Free high-efficiency power sources for urban vehicles that recently corporate by legislative initiatives. Previously, some research on modeling and simulation of PEMFC has been performed (Secanell et al. 2014). The fundamental structure of a PEMFC can be described as two electrodes (anode and cathode) separated by a solid polymer membrane that acting as an electrolyte. The hydrogen gas is the Best fuel for fuel cell powered vehicles, because of the highest conversion efficiency for fuel, generating zero tail-pipe emission and producing water as an only product of the reaction between hydrogen and air .By flowing hydrogen fuel through a network of channels to the anode, hydrogen separates into protons that transfer via the membrane to the cathode. Collection of electrons in the two electrodes causes the creation of electrical current in an electrical circuit that linked to the electrodes. Through a similar network of channels the oxygen that comes from the air, named oxidant, flows to the cathode and then, the electrons coming from the external electrical circuit will be received by oxygen and finally, produce water and heat from the protons that flow via the electrolyte membrane (Feroldi and Basualdo 2011; Gottesfeld 1999).

With a valid mathematical model, PEMFC system performance can be better understood. Moreover, the time and cost are reduced in the analysis and design of FC systems. Nowadays, programming in other sciences has a very special place because the importance of computers cannot be ignored as a very effective application in technical and research affairs. The OPEM software (open proton exchange membrane) written in Python Programming language that is very powerful for developers but is also accessible to scientists. Simulation models in PEMFC include dynamic and static models. Static models focus more on electrochemical techniques and can predict the performance of PEMFC. Simulated parametric models combined with the empirical approach that describes the important concepts such PEMFC polarization losses, efficiency, and Nernst voltage. Dynamic models improve static models and complete the simulation process. In dynamic models, the science of fluid and material merge with electrochemical principles and dynamic concepts. Consideration the rules of absorption and penetration of gases based on their pressure and density, causes the simulation of fuel cell to be more accurate and higher quality. In addition, sometimes several terms should be made for calculations regarding fuel cell efficiency–power-size. For the applied operating range of most fuel cells, a linear



**Figure 1:** Block diagram of software

estimation is practically a very good fit. Simple linear regression used for this approximation. Also applied overall parameters (such P(Thermal) and P(Electronic)) calculated by the Simpson's rule. In this software inputs are parameters that each users can specify according to the equations of each models. outputs are in the three formats CSV, HTML, and OPEM. The block diagram of software shown in figure 1.

## Supported models

Supported models include two general categories of static models and dynamic models. Static models are briefly outlined here:

### Amphlett analysis

That main concepts include Nernst voltage, PEMFC losses (activation polarization loss, ohmic polarization loss, and concentration polarization loss), power and efficiency of the fuel cell (Amphlett 1995; Correa et al. 2005; Saadi et al. 2013).

### Larminie analysis

That represent by means of voltage-current characteristic obtained in static operating mode. In fact, Larminie-Dicks static model presents the fuel cell voltage as a function of the current magnitude (Sadli et al. 2006; Saadi et al. 2013).

### Chamberline-Kim analysis

That is represented by means of its voltage-current characteristic obtained in static operating mode. In fact, Larminie-Dicks static model presents the fuel cell voltage as a function of the current magnitude (Kim 1995; Saadi et al. 2013).

And also dynamic models include:

### Padulles analysis I,II

That the temperatures and pressures of electrodes channel, transient response of cell voltage, gases outflow rates and the temperature of the cell under the sudden change in load current can be predicted. In the model I, Nernst and fuel cell potential were modeled as a function of oxygen and hydrogen gases partial pressure that can be calculated from independent variables or constants. Also in the model II, Nernst and fuel cell potential

were modeled as a function of water, oxygen and hydrogen gases partial pressure that can be calculated from independent variables or constants (Padullés, Ault, and McDonald 2000).

### Padulles-Hauer analysis

That is a model includes a methanol reformer to generate hydrogen from methanol and the PEM stack and this is an advantage for dynamic simulation of padulles analysis (Hauer 2001; Padullés, Ault, and McDonald 2000).

### Padulles-Amphlett analysis

That is an integration of Padulles-Hauer dynamic model with Amphlett static model. The superiority of this model is using Amphlett equation for simulating the polarization values (Padullés, Ault, and McDonald 2000; Hauer 2001; Amphlett 1995).

Website : [opem.ecsim.ir](http://opem.ecsim.ir)

## References

- Amphlett, J. C. 1995. "Performance Modeling of the Ballard Mark IV Solid Polymer Electrolyte Fuel Cell." *Journal of the Electrochemical Society* 142 (1). The Electrochemical Society:9. <https://doi.org/10.1149/1.2043959>.
- Correa, J.M., F.A. Farret, V.A. Popov, and M.G. Simoes. 2005. "Sensitivity Analysis of the Modeling Parameters Used in Simulation of Proton Exchange Membrane Fuel Cells." *IEEE Transactions on Energy Conversion* 20 (1). Institute of Electrical; Electronics Engineers (IEEE):211–18. <https://doi.org/10.1109/tec.2004.842382>.
- Feroldi, Diego, and Marta Basualdo. 2011. "Description of PEM Fuel Cells System." In *PEM Fuel Cells with Bio-Ethanol Processor Systems*, 49–72. Springer London. [https://doi.org/10.1007/978-1-84996-184-4\\_2](https://doi.org/10.1007/978-1-84996-184-4_2).
- Gottesfeld, Shimshon. 1999. "The Polymer Electrolyte Fuel Cell: Materials Issues in a Hydrogen Fueled Power Source." Argonne National Laboratories.
- Hauer, Karl-Heinz. 2001. "Analysis Tool for Fuel Cell Vehicle Hardware and Software (Controls) with an Application to Fuel Economy Comparisons of Alternative System Designs."
- Kim, Junbom. 1995. "Modeling of Proton Exchange Membrane Fuel Cell Performance with an Empirical Equation." *Journal of the Electrochemical Society* 142 (8). The Electrochemical Society:2670. <https://doi.org/10.1149/1.2050072>.
- Padullés, J, G.W Ault, and J.R McDonald. 2000. "An Integrated SOFC Plant Dynamic Model for Power Systems Simulation." *Journal of Power Sources* 86 (1-2). Elsevier BV:495–500. [https://doi.org/10.1016/s0378-7753\(99\)00430-9](https://doi.org/10.1016/s0378-7753(99)00430-9).
- Saadi, A., M. Becherif, A. Aboubou, and M.Y. Ayad. 2013. "Comparison of Proton Exchange Membrane Fuel Cell Static Models." *Renewable Energy* 56 (August). Elsevier BV:64–71. <https://doi.org/10.1016/j.renene.2012.10.012>.
- Sadli, I., P. Thounthong, J.-P. Martin, S. Raël, and B. Davat. 2006. "Behaviour of a PEMFC Supplying a Low Voltage Static Converter." *Journal of Power Sources* 156 (1). Elsevier BV:119–25. <https://doi.org/10.1016/j.jpowsour.2005.08.021>.

Secanell, M., A. Putz, P. Wardlaw, V. Zingan, M. Bhaiya, M. Moore, J. Zhou, C. Balen, and K. Domican. 2014. “OpenFCST: An Open-Source Mathematical Modelling Software for Polymer Electrolyte Fuel Cells.” *ECS Transactions* 64 (3). The Electrochemical Society:655–80. <https://doi.org/10.1149/06403.0655ecst>.