Fine-tuning Genetic Algorithm for Photovoltaic-Proton Exchange Membrane Fuel Cell Hybrid System Optimization

Mustapha Hatti and Hachemi Rahmani
Unité de Développement des Equipements Solaires, UDES, Centre de Développement des Energies Renouvelables, CDER,
Bou Ismail, 42415, W. Tipaza, Algeria

Keywords: PV-PEMFC Hybrid System, Fuzzy Logic Controller, Genetic Algorithm, Management, Hydrogen.

Abstract: European cities have established programs integrating the energy, transport and ICT sectors in order to deliver more efficient services for their populations. The paper tackles the study of feasibility to implement fuzzy logic control into an energetic hybrid system and to optimize the membership functions of the fuzzy logic controller for the Photovoltaic-Proton Exchange Membrane Fuel Cell hybrid system using genetic algorithm (GA). The paper deals with a fuzzy logic control strategy objective to produce electrical energy according to the demand, prone to the constraints and the dynamics of the physical load and intermittence of the energetic resource, by distributing the energy demand between the photovoltaic field and the Proton Exchange Membrane Fuel Cell system. Photovoltaic-Proton Exchange Membrane Fuel Cell is described in detail as well as system configuration and components' parameters. The second section devotes to demonstrating the design process of fuzzy logic control for Photovoltaic-Proton Exchange Membrane Fuel Cell hybrid System. Finally, the optimal control problem is addressed and genetic algorithm is introduced to help find a set of optimum parameters in the fuzzy logic controller, best results are obtained and good optimization of the hybrid system is highlighted.

1 INTRODUCTION

Smart microgrids represent currently an attractive and viable option for campus applications such as healthcare, universities, industrial and commercial complexes, small businesses, residential neighborhoods and military bases, etc (Dong, 2009).

To avoid problems caused by the weather and environmental uncertainties, the reliability of a continuous production of energy from renewable sources when only one source production system model is considered, the possibility of integrating various sources creating hybrid energy solutions can greatly reduce the intermittences and uncertainties of energy production bringing a new perspective for the near future in application on sustainable and smart cities (Angeliki Kylili, 2015). In the literature review, a sustainable energy system has been commonly defined in terms of its energy efficiency, its reliability, and its environmental impacts (Alanne, 2006). The basic requirements for an efficient energy system are its ability to generate enough power for the world needs at an affordable price, clean supply, safe and reliable conditions. On the other hand, the typical characteristics of a sustainable energy system can be derived from policy definitions and objectives since they are quite similar in industrialized countries (Mustapha Hatti, 2011). A hybrid PV-PEMFC low power system is a suitable solution to replace batteries and to supply small electric devices placed in remote areas in particularly in the industrial operations.

The improvement of the efficiency in the energy production and the guaranty of reliable energy supply seem nowadays to be common interests of developed and developing countries (Meriem Naimi-Ait-Aoudia, 2014). The application of an autonomous hybrid energy system, typically a photovoltaic PV-PEMFC hybrid power system, is a promising solution to electrifying the isolated locations far from the grid. One of the main difficulties related to the hybrid structure is the management of energy flows, (H. Ufuk Gökçe, 2014). Resolution is indeed subject to various constraints, (Ahmad Atieh, 2015), (Carlos Discoli, 2014), (Punnaiah Veeraboina, 2011), (Forrest Meggers, 2012), (Padmavathi, 2011), (Qui, 2012).

In recent years, intelligent algorithms have

Hatti M. and Rahmani H..
Fine-tuning Genetic Algorithm for Photovoltaic-Proton Exchange Membrane Fuel Cell Hybrid System Optimization.
DOI: 10.5220/0005451702340240
In *Proceedings of the 4th International Conference on Smart Cities and Green ICT Systems* (SMARTGREENS-2015), pages 234-240
ISBN: 978-989-758-105-2

become a popular optimization tool for global and numerical optimization problems, (Cheng-Hung Chen, 2008) present a functional-link-based neurofuzzy network (FLNFN) structure for nonlinear system control, which is a nonlinear combination of input variables, using an online learning algorithm, which consists of structure learning and parameter learning. Since, the structure learning depends on the entropy measure to determine the number of fuzzy rules. The parameter learning, based on the gradient descent method, can adjust the shape of the membership function and the corresponding weights of the FLNN; consequently they demonstrate the effectiveness of the FLNFN model, (Vangelis Marinakis, 2013), (Pervez Hameed Shaikh, 2014), (Marta Maria Sesana, 2015).

2 PV-PEMFC HYBRID SYSTEM

The basic PV-PEMFC structure consists of a photovoltaic generator, a PEMFC fuel cell and electrolyzer. With the hybrid structure, three modes are then possible: Load mode; Normal mode and overload mode. Charging is the discharge of the fuel cell takes place independently. (Ming-Feng Han, 2013) propose a group-based differential evolution algorithm which provides a new process using two mutation strategies to effectively enhance the search for the globally optimal solution. Were, all individuals in the population are partitioned into an elite group and an inferior group based on their fitness value. In the elite group, individuals with a better fitness value employ the local mutation operation to search for better solutions near the current best individual. The inferior group, which is composed of individuals with worse fitness values, uses a global mutation operation to search for potential solutions and to increase the diversity of the population, and GDE algorithm employs crossover and selection operations to produce offspring for the next generation.

2.1 Photovoltaïc Subsystem

The electric field created by the p-n junction causes the photon-generated electron-hole pairs to separate. The electrons are accelerated to n-region (N-type material), and the holes are dragged into p-region (P type material). The electrons from n-region flow through the external circuit and provide the electrical power to the load at the same time (Parra, D., 2014).

In this paper a simplified one diode model is used due its moderate complexity. The relationship between the output voltage V and the load current I can be expressed as:

$$I = I_L - I_D = I_L - I_o\left[\exp(\frac{U + IR_s}{a}) - 1\right] \qquad (1)$$

Where; I_L = light current (A); I_D = saturation current (A); I = load current (A); U = output voltage (V); Rs = series resistance (Ohm); a = thermal voltage timing completion factor (V). This model is called the four parameters model (1); it is simple but requires determining four parameters value which are function of temperature, load current and solar irradiance. The solar panel converts those photons into electrons of direct current ("DC") electricity. The electrons flow out of the solar panel and into an inverter and other electrical safety devices. The inverter converts that "DC" power (commonly used in batteries) into alternating current or "AC" power. AC power is the kind of electrical that electric device use when plugged into the wall outlet. PV systems likewise can be blended into virtually every conceivable structure.

Based on the mathematical equations discussed before, a dynamic model for a PV module consisting 48 cells in series has been evaluated using MATLAB/Simulink. The PV array characteristic presents three important points, the short circuit current, the open circuit voltage and the optimum power delivered by the PV to an optimum load when the PV modules operate at their MPP. The output of the Matlab function of photovoltaic model characteristics I/V and P/V is shown first for different irradiation levels (800; 600; 400; 200 W/m²) at 25°C in figures 2 and 3, and then for various temperatures (20; 30;40;50 °C) for 800 W/m² in figures 1 and 2 respectively. Results show excellent correspondence to the model.

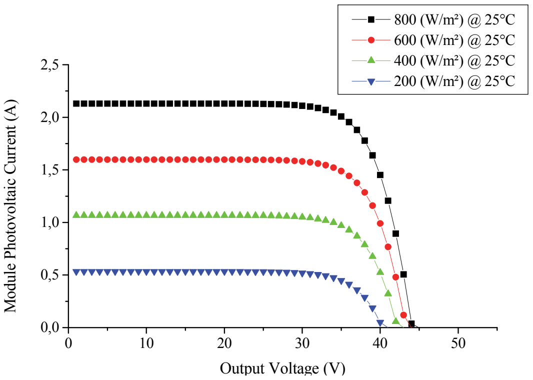

Figure 1: I/V characteristics of PV model at different irradiations and T= 25°C.

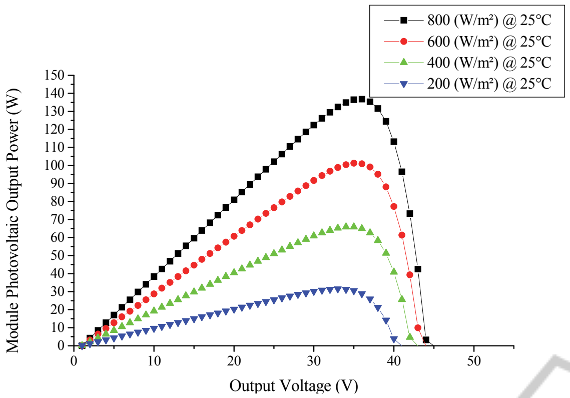

Figure 2: P/V characteristics of PV model at different irradiations and T=25°C.

2.2 Fuel Cell Subsystem

The fuel cell, as a renewable energy source, is considered one of the most promising sources of electric power. Fuel cells are not only characterized by higher efficiency than conventional power plants, but they are also environmentally clean, have extremely low emission of oxides of nitrogen and sulfur, and have very low noise.

Fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy. They have a potential to achieve a level of efficiency beyond 70% when used in a cogeneration facility. Fuel cells are classified by the type of electrolyte used in the cells and include: (1) proton exchange membrane (polymer) electrolyte fuel cell (PEMFC), (2) alkaline fuel cell (AFC), (3) phosphoric acid fuel cell (PAFC), (4) molten carbonate fuel cell (MCFC), and (5) solid oxide fuel cell (SOFC). These fuel cells are listed in the order of approximate operating temperature, ranging from 80°C for PEMFC to1000°C for SOFC.

The typical structure of a single PEMFC is shown in Figure 3. A single cell consists of anode, cathode, electrolyte plate and current collectors with gas channels. H2 and O2 get through the gas channels of currents collectors and arrive at the anode and cathode respectively; the reactive gases pass the diffusion layer and reach the proton exchange membrane(50 to 170 ptm thick) Figure 3, membrane under the action of electricity. On the cathode, the oxygen diffuses towards the catalyst interface where it combines with the hydrogen protons and the electrons to form water.

The electrons passing from anode to cathode produce electrical energy.

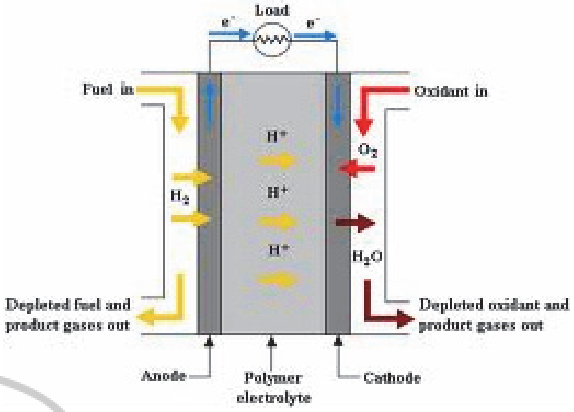

Figure 3: Schematic of PEM Fuel Cell.

In the past decades, the researches on PEMFC are mainly focused on the structural design of a single cell, catalyst layer and gas diffusion layer, the manufacture of high performance membrane and catalyst, the thermal and water management of PEM fuel cells. The researchers investigated deeply the components and PEMFC system. Different static and dynamic models of PEMFC have been established on the basis of the energy, mass and momentum conservation laws.

The components and single cell model were founded based on the operational mechanism, and research was carried out on the working parameters (gas flow rate, pressure, humidity, cell temperature and moisture content) affecting the output voltage. But the large number of experimental parameters in the models of components and single cell lead to overall decrease in performance, figures 4 and 5.

Moreover, the theoretical and simplified conditions in modeling cause the precision to decline greatly; and the expressions of model are so complex that it is difficult to apply them in the design of PEMFC system.

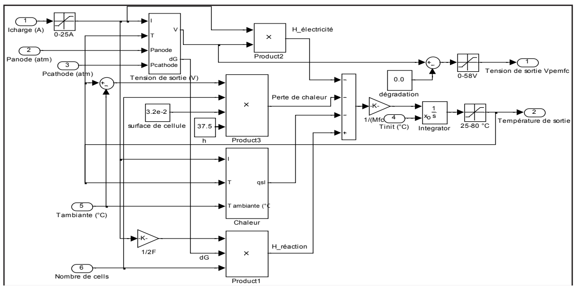

Figure 4: PEM Fuel Cell Model / MATLAB/Simulink.

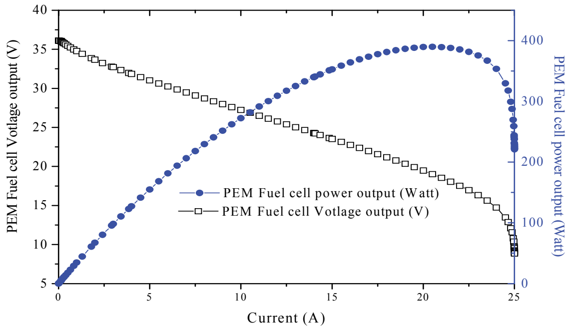

Figure 5: P/I and V/I Characteristics of PEM Fuel Cell.

2.3 Electrolyser and Hydrogen Tank Subsystem

An electrolyzer is advice that produces hydrogen and oxygen from water. The electrochemical reaction of water electrolysis is given by:

H_2O (l) + elect ene =➔ H_2 (g) + ½ O_2 (g) (2)

There are three principal types of water electrolyser:- alkaline (referring to the nature of its liquid electrolyte), proton-exchange membrane (referring to its solid polymeric electrolyte), and solid-oxide (referring to its solid ceramic electrolyte), Eq. (2). The alkaline and PEM electrolysers are well proven devices with thousands of units in operation, while the solid-oxide electrolyser is as yet unproven.

The PEM electrolyser is particularly well suited to highly distributed applications. The alkaline electrolyser currently dominates global production of electrolytic hydrogen.

Alkaline water elecrolysis is the dominating technology today. According to faraday' law, hydrogen production rate of an electrolyser can be obtained as:

$$n_{H_2} = \frac{\eta_F n_C i_e}{2F} \tag{3}$$

Where: F: Faraday constant, i_e: Electrolyser current, n_C: The number of electrolyser cells in series, η_F: Faraday efficiency.

n_{H2}: Produced hydrogen moles per second, Eq. (3).

One of the hydrogen storage techniques is physical hydogen storage, which involves using tanks to store either compressed hydrogen gas or liquid. The hydrogen storage model based on Eq. (4) directly calculates the tank pressure using the ration of hydrogen flow in the tank. The produced hydrogen is stored in the tank, whose system dynamic can be compressed as follow:

$$P_b - P_{bi} = z\frac{N_{H_2} R T_b}{M_{H_2} V_b} \tag{4}$$

Where: M_{H2}: Molar mass of hydrogen; N_{H2}: Hydrogen moles per second delivered to the storage tank; P_b: Pressure of tank.

P_{bi}: Initial pressure of the storage tank; R: Universal gas constant; T_b: Operating temperature; V_b: Volume of the tank; z: Compressibility factor as a function of pressure, Eq. (4); The hydrogen' state-of-storage (SHS) is therefore:

$$SHS = \frac{P_b}{P_{b\max}} \tag{5}$$

Where: P_b: Pressure of tank; P_{bmax}: is the maximum Pressure of the tank, Eq. (5).

3 FUZZY LOGIC CONTROLLER AND GENETIC ALGORITHM

Since, the wanted behaviour is well known and can be described using linguistic variables; the use of a FLC seems appropriate (Shinq-Jen Wu, 2002).

However, it is shown that the method of the average maximum ensures better performance of transition (Cheng-Hung Chen, 2008).

It emerges through these comparative studies that the choice of a better method of defuzzification is highly dependent on the particular application, and is the case of the maximum like method which proves to be very effective for control problems (T. Azib, 2010).

Simulink block that focused energy management of a PV-PEMFC hybrid system is implemented:

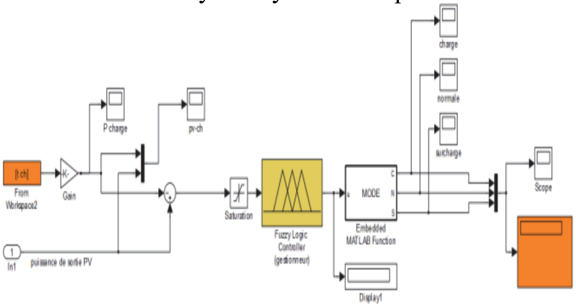

Figure 6: Energy management system bloc diagram.

This system acts as a fuzzy controller that controls the operation mode of our hybrid system regardless of load variations, and photovoltaic generator, in figure 6. The result is obtained varies with the error representing the difference between load power and power of photovoltaic generator can therefore defined three operating mode in this system, namely:

- *Normal Mode*: In this mode, the power of positive charge is below the maximum power from the main source, in this mode the photovoltaic generator can only feed the load.
- *Overload*: In this mode the power absorbed by the load is above the main power source, the controller can recognize the power of the fuel cell to the load.
- *In Charge Mode* (recovery): In this mode, the power of a PV generator exceeds the load power. The changes in operating mode only occur when the load demand is at the boundary of mode Change. This type of controllers presents many advantages for this system.

3.1 Genetic Algorithm Optimisation

For the current study, the objective function is the net power, which is defined as the ratio of the net electrical power output of the system compared to the energy power demand to the system, which is quantified by the value of the variable that is to be minimized. Summarily, the methodology of the genetic algorithm consists of the following steps:

1. Generate a random population and evaluate the fitness of each member;
2. Define the termination conditions;
3. Select parents if the crossover condition is met, select crossover parameters and apply crossover;
4. Select member if the mutation condition is met, select mutation parameters and apply mutation;
5. Evaluate the fitness of the offspring and update the population;
6. Repeat steps 2-6, until the termination conditions are satisfied.

4 RESULTS AND COMMENTS

Figure 7 shows the residential power demand profile and solar resources of 48 hours, (Wood Christopher J. 2010).

The optimum configuration of the hybrid system proposed is presented and outputs of the Fuzzy logic controller are depicted in figure.8, following the behavior of the energetic system. The objective function has been significantly improved in figures 9-11.

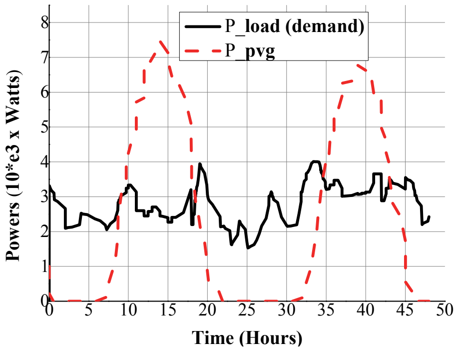

Figure 7: Output of PV generator (PgPV) and load profile (Pch).

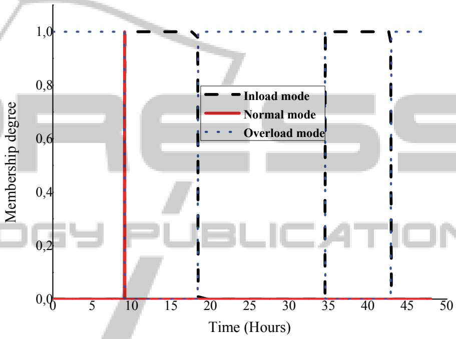

Figure 8: Fuzzy logic control operations.

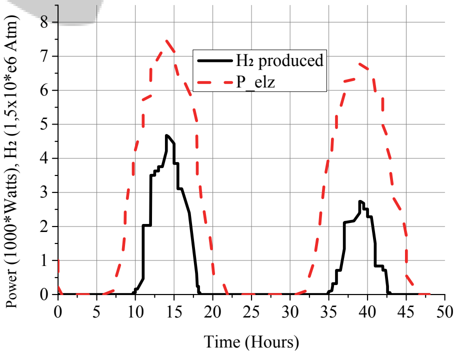

Figure 9: Load mode and Hydrogen produced.

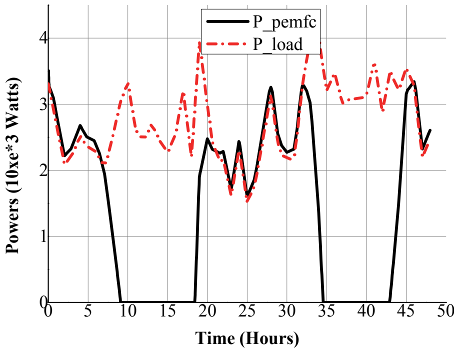

Figure 10: Overload mode.

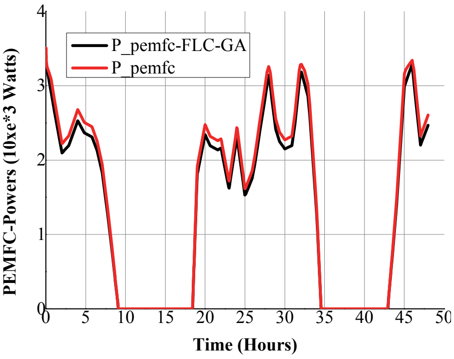

Figure 11: PEM Fuel Cell power distribution within 48 hours.

The improvement is more noticeable in the beginning of the optimization process; this flat behavior indicates that the overall iterative optimization scheme has practically converged.

5 CONCLUSIONS

In this paper the set model of the stand alone PV-PEM Fuel Cell hybrid system is analyzed and then one fuzzy logic controller is considered.

A genetic algorithm is introduced to fine-tune parameters of membership functions in the fuzzy logic controller. The results show that the hybrids with the fine-tuned fuzzy logic controller would have a higher fuel economy and better system efficiency compared with the rule-based controller.

The fuzzy logic controller is then designed to handle with energy distribution and management. To achieve improved equivalent fuel consumption, genetic algorithm is implemented to fine-tune the membership functions.

The control effects must be compared between different control strategies, e.g. rule-based control and fine-tuned fuzzy logic control in next future work.

The results point out those hybrids energetic systems with the proposed strategy can improve fuel economy without sacrificing system performance.

REFERENCES

Dong Leilei, Liu Hao, et Riffat Saffa. Development of small-scale and micro-scale biomass-fuelled CHP systems–A literature review. *Applied thermal engineering*, 2009, vol. 29, no 11, pp. 2119-2126.

Angeliki Kylili, Paris A. Fokaides European smart cities: The role of zero energy buildings *Sustainable Cities and Society, 15, 2015,* pp. 86-95.

Naimi-Ait-Aoudia, M., & Berezowska-Azzag, E. (2014). Algiers carrying capacity with respect to per capita domestic water use. *Sustainable Cities and Society*, 13, pp. 1-11.

M Hatti, A Meharrar, M Tioursi, Novel approach of maximum power point tracking for photovoltaic module neural network based, *Int. Symposium on Environment Friendly Energies in Electrical Applications*, 1-6.

Alanne, K. and Saari, A. Distributed energy generation and sustainable development. *Renewable & Sustainable Energy Reviews*, vol. 10, issue 6, 2006, pp.539-558.

H. Ufuk Gökçe, K. Umut Gökçe, Multidimensional energy monitoring, analysis and optimization system for energy efficient building operations, 2014, *Sustainable Cities and Society*, 10, pp 161-173.

Ahmad Atieh, Samir Al shariff, Case study on the return on investment (ROI) for using renewable energy to power-up typical house in Saudi Arabia, Sustainable Cities and Society xxx (2015) xxx–xxx, article in press.

Carlos Discoli, Irene Martini, Gustavo San Juan, Dante Barbero, Luciano Dicroce, Carlos Ferreyro, Jésica Esparza, Methodology aimed at evaluating urban life quality levels Sustainable Cities and Society, Volume 10, February 2014, Pages 140-148.

Punnaiah Veeraboina, G. Yesuratnam, L. Syam Sundar, Estimation of Annual Solar Radiation from measured temperatures by using Temperature-based (TB) approach in different cities in India Sustainable Cities and Society, Vol. 1, Issue 4, 2011, pp. 187-194.

Forrest Meggers, Hansjürg Leibundgut, Sheila Kennedy, Menghao Qin, Mike Schlaich, Werner Sobek, Masanori Shukuya, Reduce CO_2 from buildings with technology to zero emissions, Sustainable Cities and Society, Vol. 2, Issue 1, 2012, pp. 29-36.

K. Padmavathi, S. Arul Daniel, Studies on installing solar water pumps in domestic urban sector Sustainable Cities and Society, Vol. 1, Issue 3, 2011, Pages 135-141.

Qiu, Guoquan, Shao, Yingjuan, LI, Jinxing, S.B. Riffat. Experimental investigation of a biomass-fired ORC-based micro-CHP for domestic applications. *Fuel*, 2012, vol. 96, p. 374-382.

Cheng-Hung Chen; Cheng-Jian Lin; Chin-Teng Lin, A Functional-Link-Based Neurofuzzy Network for Nonlinear System Control, *IEEE Transactions on Fuzzy Systems,* Vol.16, N. 5, 2008, pp. 1362 – 1378.

Vangelis Marinakis, Charikleia Karakosta, Haris Doukas, Styliani Androulaki, John Psarras, A building automation and control tool for remote and real time monitoring of energy consumption, Sustainable Cities and Society, Vol. 6, 2013, pp. 11-15.

Pervez Hameed Shaikh, Nursyarizal Bin Mohd Nor, Perumal Nallagownden, Irraivan Elamvazuthi, Stochastic optimized intelligent controller for smart energy efficient buildings, Sustainable Cities and Society, Vol. 13, 2014, pp. 41-45.

Marta Maria Sesana, Branka Cuca, Giuliana Iannaccone, Raffaella Brumana, Dominique Caccavelli, Charly Gay, Geomapping methodology for the GeoCluster Mapping Tool to assess deployment potential of technologies for energy efficiency in buildings, Sustainable Cities and Society, Vol. 17, 2015, pp. 22-34.

Mustapha Hatti, A. Meharrar, M. Tioursi Power management strategy in the alternative energy photovoltaic/PEM Fuel Cell hybrid system *Renewable and Sustainable Energy Reviews*, vol. 15, Issue 9, 2011, pp. 5104-5110.

Parra, D., Walker, G. S., & Gillott, M., 2014. Modeling of PV generation, battery and hydrogen storage to investigate the benefits of energy storage for single dwelling. *Sustainable Cities and Society*, 10, 1-10.

Shinq-Jen Wu; Chin-Teng Lin, Global optimal fuzzy tracker design based on local concept approach, *IEEE Transactions on Fuzzy Systems*, Vol.10, N° 2, 2002 , pp. 128 – 143.

Shun-Chung Wang, Yi-Hwa Liu, "A Modified PI-Like Fuzzy Logic Controller for Switched Reluctance Motor Drives ," *IEEE Trans. on Industrial Electronics,* vol. 58, no. 5, 2011, pp. 1812 - 1825.

Azib T., O. Bethoux, G. Remy, C. Marchand, E. Berthelot, "An Innovative Control Strategy of a Single Converter for Hybrid Fuel Cell/Supercapacitor Power Source", *IEEE Trans. on Industrial Electronics,* vol. 57, no. 12, 2010, pp. 4024–4031.

Wood, Christopher J., Liu, Hao, et Riffat Saffa B. An investigation of the heat pump performance and ground temperature of a piled foundation heat exchanger system for a residential building. *Energy*, 2010, vol. 35, no 12, p. 4932-4940.