Grid Integration of Hybrid Generation

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Abstract- The wind and solar energies are the most available among other renewable energy sources in all over the world. In the present years, because of the rapid advances of power electronic systems the production of electricity from wind and photovoltaic energy sources have increased significantly. In this paper, the performance of the wind/PV hybrid system is studied under different grid perturbation conditions. Based on the benchmark solid oxide fuel cell (SOFC) dynamic model for power system studies and the analysis of the SOFC operating conditions, the nonlinear programming (NLP) optimization method was used to determine the maximum electrical efficiency of the grid-connected SOFC subject to the constraints of fuel utilization factor, stack temperature and output active power. The optimal operating conditions of the grid-connected SOFC were obtained by solving the NLP problem considering the power consumed by the air compressor. With the optimal operating conditions of the SOFC for the maximum efficiency operation obtained at different active power output levels, a hierarchical load tracking control scheme for the grid-connected SOFC was proposed to realize the maximum electrical efficiency operation with the stack temperature bounded. The hierarchical control scheme consists of a fast active power control and a slower stack temperature control. The active power control was developed by using a decentralized control method. The efficiency of the proposed hierarchical control scheme was demonstrated by case studies using the benchmark SOFC dynamic model

Keywords – SOFC, PV Cell, NLP Method

I. Introduction

The deregulation of electric power utilities, environmental concerns, market uncertainty and growing concern about availability and quality of electrical power has led to development of distributed generation system. One of the well-known DG sources is a fuel cell, which can be operated in utility interconnected mode or installed in a remote area to supply separate power. Recently, much work has been focused on interfacing DG with the grid, its operation and control. A flexible DG can be used to improve the power factor and voltage fluctuations of the utility. SOFC based DG System is normally interfaced with the utility network through a set of power electronics devices. The interface is very important as it affects the operation of the fuel cell system and the power grid[1]. Various control schemes haven proposed in the recent work to interface different energy sources to utility grid Pulse– width modulation voltage source inverters are widely used to interconnect a fuel cell energy system to a utility grid for real and reactive power control purpose. The growing lack of fossil fuels, the increasing demand for electricity and the dangerous effect of carbon dioxide output on the climate force nations - specially industrialized countries and their governments - to find new ways of producing the amount of energy in demand. The integration of alternative energies to reduce emissions and to conserve available fossil sources is a known political aim. Although the potential of renewable is very high and the technical conditions to produce electricity are achieved, the current generated rates are clearly lower. A key problem is the integration of renewable energies into the existing grid. This paper analyzes the reasons for this deficit and assesses possible solutions.

A Hybrid Power System (HPS) utilizes two or more energy sources, power converters and/or storage devices. The main purpose of HPS is to combine multiple energy sources and/or storage devices which are complement of each other. Thus, higher efficiency can be achieved by taking the advantage of each individual energy source and/or device while overcoming their limitations [2]. Recent advancement in FC technology for grid enhancement has exposed its significant potential and consider an indispensable energy source for the future power system. FC is a static energy source that generates electricity from hydrogen through electrolysis. The superior reliability, with practically zero noise level or no moving parts is an extra advantage of FC system as compared to the diesel generator. Main characteristics of FC include modularity, near zero emissions, fuel flexibility, premium power quality, high efficiency and practically low noise levels. Other advantages of FC are the distributed and centralized configurations, diversity of fuels, cogeneration options and reusability of exhaust gases for heating of buildings [3]. The combined use of FC with an Electrolyser (ELZ), hydrogen storage tanks and compressor unit provide a new energy storage concept. Since, hybridization of FC stacks with PV panels will, therefore, form an alternate energy conversion system where the FC acts as back up during low PV outputs to satisfy sustained load demands. There are several types of FCs which are classified on the basis of their operating temperature ranges and type of electrolyte. In this study, Solid Oxide Fuel Cell (SOFC) is selected, because, it works at high temperatures (800 – 1000 °C) [4]. But, the main weak point in SOFC is their poor dynamic response, gas starvation and load tracking delays [5]. When a SOFC is subjected to a step increase in load, it shows an instant drop off of the voltage in the V-I curve and take several seconds to provide the desired power. In the meantime, the SOFC may be starved of fuel, which can seriously affect the life time of SOFC [6]. This problem can be addressed by using a high energy density device such as a battery. Therefore, the SOFC should be utilized under controlled steady-state environment while the battery is supplying the demanded power. Without the battery bank, the SOFC system must provide all the power demand, thus oversize and increase the cost of the SOFC power plant.

II. LITERATURE REVIEW

In this research work [7], design and control strategy of an autonomous photovoltaic fuel-cell energy system has been developed and simulations have been performed in order to supply electricity to a DC-load without being connected to the electric grid. In this [8]the authors presented modelling and control of photovoltaic/wind/fuel cells hybrid generating system. The overall work is divided into two parts. In the first part the authors focused on each subsystem and different parameters are identified for each subsystem. The second part dealt with the design and installation of various equipment which includes voltage and current sensors, the data acquisition is made possible by using National Instruments cards which allowed to obtain real time data in Lab VIEW environment The energy system having a photo voltaic (PV) panel, wind turbine and fuel cell (SOFC) for continuous power flow management. Fuel cells (storage & generating) are added to ensure uninterrupted power supply due to the discontinuous nature of solar and wind resources. This paper [9] proposes a design and modelling of grid connected hybrid renewable energy power generation. The energy system having a photo voltaic (PV) panel, wind turbine and fuel cell (SOFC) for continuous power flow management. Fuel cells (storage & generating) are added to ensure uninterrupted power supply due to the discontinuous nature of solar and wind resources.There are some drawbacks in all the above mentioned studies. For example, some authors include short energy system in their studies, while others concentrate on long term storage medium. Some authors describe power control of PV system while others attempt to address the energy management without providing power sharing among different energy sources and/or storage system. In addition to this, most of the authors supported their studies on the basis of virtual generated solar irradiance, temperature and weather patterns.

III. RENEWABLE ENERGY SOURCES

1. SOLAR ENERGY -The solar energy is an unlimited source of energy which is originated from the sun. When the light and heat from the sun are used directly without changing the form, then the technology refers as a direct or passive technology of solar energy and when it used by converting the form of energy, that is called indirect or active technology of solar energy. The photovoltaic technology is the renowned indirect way and the solar thermal system is the direct way to harvest the abundant energy. There are different options for producing electricity from renewable energy sources. Consequently, there are several ways of connecting the gained electricity with the existing grid.

2. WIND ENERGY - Wind energy is the energy which is extracted from wind. For extraction we use wind mill. It is renewable energy sources. The wind energy needs less cost for generation of electricity. Maintenance cost is also less for wind energy system. Wind energy is present almost 24 hours of the day. It has less emission. Initial cost is also less of the system.

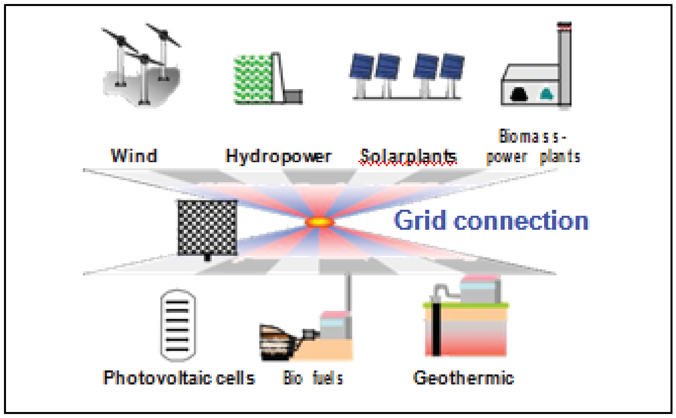

Figure 1. Grid Connection

Preferred sources are wind, hydro, solar, biomass, photovoltaic cells, bio fuels and geothermic as shown in Fig. 1. The electricity is induced by asynchronous or synchronous generators except for photovoltaic cells. This operation creates co-current flows and gets through an inverted rectifier into the power grid.

IV. GRID INTERFACE TOPOLOGY OF SOFC

Fuel cells are electrochemical energy conversion devices similar to batteries. They generate variable and low output voltage (current). Thus, they are unable to connect to the utility directly. However, they can be interfaced and can supply power to the utility by means of power electronic converters Fig. 2. Shows system integration of fuel cell and power electronics unit which comprises of a solid oxide fuel cell stack associated with a DC –DC converter and a widely used DC–AC pulse width modulation (PWM) inverter with RL output filter connected to the utility grid. In this chapter of the work, the case of a SOFC based DG connected to a grid is considered wherein the capacity of power supply by the DGs is less than the load demand i.e., the active power demand of load is more than DG capacity and hence grid and DG both will supply active power to the load. Thus, in this mode of operation a certain amount of power is scheduled to the load from the fuel cell DG and remaining power to load is supplied from the utility grid.

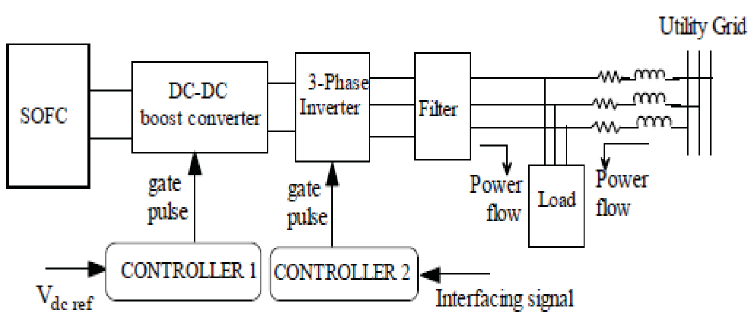

Figure 2. Schematic diagram of grid connected DGs

The DGs autonomously operate with load until it reaches the steady-state. The phase difference between the DGs output voltage and the grid voltage decreases until the DGs output voltage is in phase with the grid voltage. After the DGs output voltage is synchronized with the grid voltage, the grid is connected to DGs and then the grid starts providing electric power to the load. There are various control strategies for interfacing DGs to the distribution system. The DG is operated either to control DG output current, active power and voltage at the point of common coupling (P-V mode) or active and reactive power output of DG.

V. INTEGRATION IN EXISTING GRID

To understand the problem of why the potential of renewable energy sources is not exhausted, you have to consider the actual grid conditions and the resulting barriers. The public electricity supply in most European countries presents an extensive central configuration. Grids are designed to transmit electricity generated by large conventional power plants. An aggregation occurs by using transformers between the transmission and the distribution grid. At the end is the consumer. The interconnection directly or indirectly allocates the electricity to connected users in a central way. In the distribution grid the voltage falls in the direction of the current flow. The decline depends on resistance and inductance in the cable. These two factors grow with rising cable length. To provide all consumers with enough voltage, a transformer slightly increases the voltage at the beginning of a cable. Energy generation from renewable sources requires an installation of the plant in locations with a high energy supply, for example, in areas with a grand wind velocity. Therefore, the installations are connected at different local points to the grid. In contrast to large power plants, renewable plants have less capacity and are integrated in lower grid levels. When decentralized generators integrate electricity in low-voltage lines, conditions can change and the power flows in the direction of the transformer. Voltage rise aggravates in practice if more and more distributed generators, especially in pastoral areas with mostly weak grids, are integrated. This barrier of insufficient grid capacity available for renewable energy is the main problem. The integration of distributed energy producers seriously influences the operation of the whole grid and calls for new requirements of the mains operation. For example, in Germany the "Erneuerbaren-Energien-Gesetz" (EEG) requires the permanent input of available energy from distributed renewable plants. Thus central large power plants are forced to work in part load and have additional starts. These actions have negative effects on materials, efficiency, costs of generation and lead to additional input of fossil fuels and output of carbon dioxide. To avoid voltage rises, the grid has to be partly extended. The costs of grid reinforcement are often very high. The benefits of producing energy from renewable sources are often considered less important than the costs. Moreover, alternative power developers have highlighted that it is impossible to determine the available grid capacity so that they are unable to verify the technical and cost data of the grid connection presented to them by the grid operator. Furthermore, Distribution System Operators (DSO) are often linked to electricity generation companies. It is disputable whether such a DSO is fully objective towards independent renewable energy producers when the electricity generation company is involved in developing alternative energy programs. The insufficient transparency of grid connection causes long lead times to obtain grid connection authorization. Polls show that stakeholders' perceptions of grid barriers per renewable energy source are very high.

VI. GRID INTEGRATION OF HYBRID SYSTEM

The integration of combined solar and wind power systems into the grid can help in reducing the overall cost and improving reliability of renewable power generation to supply its load. The grid takes excess renewable power from renewable energy site and supplies power to the site' loads when required. Common DC and common AC bus grid-connected to solar PV and wind hybrid system, respectively. The complete system is designed in two buses i.e., DC and AC bus. PV, SOFC, ELZ and battery make the architecture of DC bus, and the power conversion and transferring occurs between these components through a CEMCA. Domestic load and national grid are the parts of AC bus. The output voltages of PV and SOFC are regulated and adjusted through two non-isolated DC–DC boost converters. The boost converter is controlled through Proportional Integral Differentiator (PID) controller. The bidirectional power flow of battery with the rest of the system occurs through a buck boost converter. The buck boost converter is controlled through Proportional Integral (PI) controller. The output of DC bus provides the required power to the grid and grid-connected load through three phase inverter even if only one source is available. The inverter is controlled via hysteresis current control strategy. It is important to describe that the proposed HPS is flexible and, therefore, easily upgradable as long as a new PV, SOFC and battery are added to the existing ones without increasing the circuit complexity. Furthermore, it is also possible to add another parallel inverter to expend the said design with high efficiency[10]as shown in Fig 3.. The assessment of the performance and stability of the proposed CEMCA necessitates the simulation of the integrated system over a period of time. Therefore, steady-state simulation models have been employed for each distinct unit.

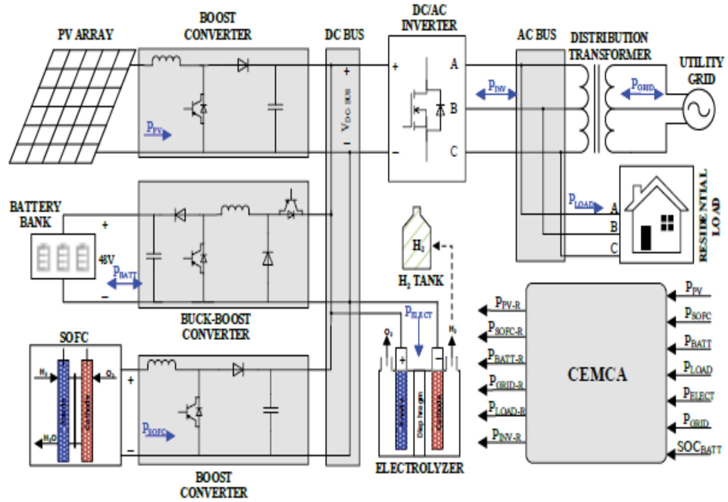

Figure 3. Architecture Of Proposed Hybrid Power System

TABLE 1. MAIN CHALLENGES AND POSSIBLE SOLUTIONS FOR GRID-CONNECTED SYSTEM

SR. NO.	AUTHER'S NAME	CHALLENGES	SOLUTIONS
1.	B. Emst, F. Reyer, and J. Vanzetta[11]	Voltage fluctuation due to variations in wind speed and irregular solar radiation	Series and shunt active power filters.
			Power compensators.
	S. K. Khadem, M. Basu, and M. F. Conlon [12]		Fixed/switched capacitor or static compensator.
	N. T. Linh [13]		Less sensitive customer's equipment to power disturbance/voltage distortions and utilities line conditioning systems.
2.	F. O. Resende and J. A. P. Lopes [14]	Frequency fluctuation for sudden changes in active power by loads	PWM inverter controller for regulating frequency in a micro grid.
3.	B. Emst, F. Reyer, and J. Vanzetta[11][12][13]	Harmonics by power electronics devices and non-linear appliances.	PWM switching converter and appropriate filters.
4.	B. Emst, F. Reyer, and J. Vanzetta[11], B. Emst, F. Reyer, and J. Vanzetta [15]	Intermittent energy's impacts on network security	Accurate statistical forecasting and scheduling systems. Regression analysis approaches and algorithms for forecasting weather pattern, solar radiation and wind speed.
	D. A. Halamay, T. K. A. Brekken [16]		Increase or decrease dispatch able generation by system operator to deal with any deficit/surplus in renewable power generation.
	Y. J. Liu and C. W. Jiang [17] E.F. Camacho, T. Samad, M. Garcia-sanz, and I. Hiskens[18]		Advanced fast response control facilities such as Automatic Generation Control and Flexible AC Transmission System.
5.	B. Emst, F. Reyer, and J. Vanzetta[11]	Synchronization	The most popular grid synchronization technique is based on phased-locked loop. Other techniques for synchronization include detecting the zero crossing of the grid voltages or using combinations of filters coupled with a non-linear transformation.

TABLE 2. MAIN CHALLENGES AND POSSIBLE SOLUTIONS FOR STAND-ALONE SYSTEM

SR. NO	AUTHER'S NAME	CHALLENGES	SOLUTIONS
1.	B. S. Borowy and Z. M. Salameh [19] Z. M. Salameh and B. S. Borowy [20]	High storage cost	Combining both PV solar and wind power will minimum the storage requirements and ultimately the overall cost of the system.
2.	R. Chedid and Y. Saliba [21]	Less usable energy during the year.	Integration of renewable energy generation with battery storage and diesel generator back-up systems.
3.	R. Chedid and Y. Saliba [21] A. N. Celik [22]	Intermittent energy / power quality	Integration of renewable energy generation with battery storage or fuel cell and in some cases with diesel generator back-up systems.
4.	A. N. Celik [22]	Protection	Suitable protection devices need to be installed for safety reasons including up grading of existing protection scheme in particular when distributed generators are introduced.
5.	D. B. Nelson, M. H. Nehrir, and C. Wang [23] N. A. Ahmed, M. Miyatake, and A. K. Al-Othman [24]	Storage runs out	Integrate PV and wind energy sources with fuel cells.
6.	D. B. Nelson, M. H. Nehrir, and C. Wang [23] N. A. Ahmed, M. Miyatake, and A. K. Al-Othman [24]	Environmental and safety concerns of batteries and hydrogen tanks.	Integrating PV and wind energy sources with fuel cells instead of large lead-acid. Batteries or super storage capacitors, leads to a non polluting reliable energy source. and reduces the total maintenance costs.

VII. CONCLUSION

The performance of SOFC based DG system connected to grid has been carried out. In grid-connected mode, the voltage and frequency are controlled by the grid. Thus, the DG units are controlled to provide specified amount of real power depending upon the rating of the units. A control strategy has been developed using decouple method to control the active and reactive powers independently from the solid oxide fuel cell. This paper has provided a review of challenges and opportunities on integrating solar PV and wind energy sources for electricity generation. The main challenge for grid-connected system as well as the stand-alone system is the intermittent nature of solar PV and wind sources.

REFERENCES

[1] P. Kammer, A. Kober, "Grid integration of renewable energy sources", *International Journal of Distributed Energy Resources, Volume 2, Number 1, 2006, S. 59-81)*

[2] S. Rehman and L. M. Al-Hadhrami, "Study of a solar PV–diesel–battery hybrid power system for a remotely located population near Rafha, Saudi Arabia," *Energy*, 35(12): 4986–4995 (2010).

[3] T. F. El-Shatter, M. N. Eskandar, and M. T. El-Hagry, "Hybrid PV/fuel cell system design and simulation," 2002.T. Das and S. Snyder, "Adaptive control of a solid oxide fuel cell ultra-capacitor hybrid system," in *Proceedings of the 2011 American Control Conference*, 3892–3898 (2011). T. Allag and T. Das, "Robust Control of Solid Oxide Fuel Cell Ultracapacitor Hybrid System," *IEEE Trans. Control Syst. Technol.*, 20(1): 1–10 (2011).

[4] P. Thounthong and P. Sethakul, "Analysis of a Fuel Starvation Phenomenon of a PEM Fuel Cell," in *2007 Power Conversion Conference - Nagoya*, 731–738 (2007).

[5] N. Mezzai, D. Rekioua, T. Rekioua, A. Mohammedi, K. Idjdarane, and S. Bacha, "Modeling of hybrid photovoltaic/wind/fuel cells power system," *Int. J. Hydrogen Energy*, 39(27): 15158–15168 (2014).

[6] N. Mezzai, D. Rekioua, T. Rekioua, A. Mohammedi, K. Idjdarane, and S. Bacha, "Modeling of hybrid photovoltaic/wind/fuel cells power system," *Int. J. Hydrogen Energy*, 39(27): 15158–15168 (2014).

[7] Design and Modeling of Grid Connected Hybrid Renewable Energy Power Generation *M. Kishore Reddy et al Int. Journal of Engineering Research and Applications* www.ijera.com *ISSN : 2248-9622, Vol. 4, Issue 9(Version 5), September 2014, pp.158-164 ,*

[8] Tariq Kamal*,1, Syed Zulqadar Hassan2 ," Energy Management and Simulation of Photovoltaic/Hydrogen/Battery Hybrid Power System ",*T. Kamal et al. / Advances in Science, Technology and Engineering Systems Journal Vol. 1, No. 2, 11-18 (2016)*

[9] B. Ernst, F. Reyer, and J. Vanzetta, "Wind power and photovoltaic prediction tools for balancing and grid operation," *Proc. Integration of Wide-Scale Renewable Resources Into the Power Delivery System, CIGRE/IEEE PES Joint Symposium,* IEEE Press, pp. 1-9, July (2009).

[10] S. K. Khadem, M. Basu, and M. F. Conlon, "Power quality in grid connected renewable energy systems : Role of custom power devices," *Electric Power Research Group, School of Electrical Engineering Systems, Dublin Institute of Technology* (2010)

[11] N. T. Linh, "Power quality investigation of grid connected wind turbines," *Proc. 4th IEEE Conference on Industrial Electronics and Applications (ICIEA 09)*, IEEE Press, pp. 2218-2222, May (2009) DOI: 10.1109/ICIEA.2009.5138593

[12] F. O. Resende and J. A. P. Lopes, "Management and control systems for large scale integration of renewable energy sources into the electrical networks," *Proc. IEEE International Conference on Computer as a Tool (EUROCON 11)*, IEEE Press, pp. 1-6, April (2011) DOI: 10.1109/EUROCON.2011.5929423

[13] B. Ernst, F. Reyer, and J. Vanzetta, "Wind power and photovoltaic prediction tools for balancing and grid operation," *Proc. Integration of Wide-Scale Renewable Resources Into the Power Delivery System, CIGRE/IEEE PES Joint Symposium, IEEE Press*, pp. 1-9, July (2009)

[14] D. A. Halamay, T. K. A. Brekken, A. Simmons, and S. Mcarthur, "Reserve requirement impacts of large-scale integration of wind, solar and ocean wave power generation" *IEEE Transactions on Sustainable Energy*, 2, 321-328 (2011) DOI: 10.1109/TSTE.2011.2114902

[15] Y. J. Liu and C. W. Jiang, "A review on technologies and methods of mitigating impacts of large-scale intermittent renewable generations on power system" *Research Journal of Applied Sciences, Engineering and Technology*, 5, 2765-2770 (2013)

[16] E.F. Camacho, T. Samad, M. Garcia-sanz, and I. Hiskens, "Control for renewable energy and smart grids,"http://web.eecs.umich.edu/~hiskens/publications/IoCTPart1- 06RESG.pdf, (2011).

[17] B. S. Borowy and Z. M. Salameh, "Methodology for optimally sizing the combination of a battery bank and PV array in a

[18] Wind/PV hybrid system" *IEEE Transactions on Energy Conversion*, 11, 367-375 (1996) DOI: 10.1109/60.507648

[19] Z. M. Salameh and B. S. Borowy, "Optimum photovoltaic array size for a hybrid wind/PV system" *IEEE Transactions on Energy Conversion*, 9, 482-488 (1994) DOI: 10.1109/60.326466

[20] R. Chedid and Y. Saliba, "Optimization and control of autonomous renewable energy systems" *International Journal Of Energy Research*, 20, 609-624 (1996) DOI:10.1002/(SICI)1099-114X(199607)20:7<609::AIDER176> 3.0.CO;2-O.

[21] N. Celik, "Optimisation and techno-economic analysis of autonomous photovoltaic-wind hybrid energy systems in comparison to single photovoltaic and wind systems" *Energy Conversion and Management*, 43, 2453-2468 (2002) DOI: 10.1016/S0196-8904(01)00198-4.

[22] D. B. Nelson, M. H. Nehrir, and C. Wang, "Unit sizing and cost analysis of stand-alone hybrid wind/PV/fuel cell power generation systems" *Renewable Energy*, 31, 1641-1656 (2006) DOI: 10.1016/j.renene.2005.08.031N.

[23] A. Ahmed, M. Miyatake, and A. K. Al-Othman, "Power fluctuations suppression of stand-alone hybrid generation combining solar photovoltaic/wind turbine and fuel cell systems" *Energy Conversion and Management*, 49, 2711-2719, (2008) DOI:10.1016/j.enconman.2008.04.005