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A Hybrid Power System using Solid oxide Fuel cell, PV arrays, Electrolyzer and Ultra-Capacitor

*Suhaila Shahnaz AA, Dona Jose**

Department of Electrical and Electronics Engineering, Al Ameen College of Engineering, Shornur, Kerala, India
** Corresponding Author email : josedona6@gmail.com*

ABSTRACT

This paper presents an integration and power control of hybrid power system combining a Photo Voltaic arrays ,SOFC Stack, ,an Electrolyzer (ELZ) and an energy storage system in the form of hydrogen tanks and an UC module . The photovoltaic generator is chosen for its positive points including being carbon free and inexhaustible .Solid Oxide Fuel Cell (SOFC) is a promising green power source and offers various benefits such as modularity, high efficiency and cogeneration options. but the demerits such as slow dynamics and gas starvation problems affects the performance of SOFC. Due to which the SOFC fails in providing fast response and also face load following problems. However, an integration of SOFC with complementary device such as an Ultra-capacitor (UC) can solve these problems. A dynamic power flow controller is designed which supervised and managed all the energy sources and power converters to maximize the use of SOFC/ELZ/UC and reduce burden on the grid. According to this strategy PV and SOFC has priority in meeting load demand. The UC is utilized as a complement and/or backup device to cover the slow dynamics of the SOFC during transient, while the ELZ is used as a dump load to generate hydrogen for SOFC during surplus power. The proposed system is synchronized to the grid through power electronic converters to enhance the reliability and continuity of power. The performance of the proposed system is investigated under real-world record of load conditions.

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1. Introduction

At present, most of energy demand in the world relies on fossil fuels such as petroleum, coal, and natural gas that are being exhausted very fast. One of the major severe problems of global warming is one of these fuels combustion products, carbon dioxide; these are resulting in great danger for life on our planet [2] Fossil fuels can have as an alternative some renewable energy sources like solar, wind, biomass, and so; among them on the photovoltaic (PV) generator which converts the solar radiation into electricity, largely used in low power applications. The photovoltaic generator is chosen for its positive points including being carbon free and inexhaustible moreover, it does not cause noise for it is without moving parts and with size-independent electric conversion efficiency[3]. Nevertheless, the power generated by a PV system is influenced by weather conditions; for example, at night or in cloudy periods, it would not generate any power or application. In addition, it is difficult to store the power generated by a PV system for future use. The best method to overcome this problem is to integrate the PV generator with other power sources such as an electrolyser, hydrogen storage tank, FC system, or battery due to their good features such as high efficiency response, modular production, and fuel flexibility [4, 5] Fuel cells are electrochemical devices for energy conversion with a very high electrical efficiency, higher than 50% fuel flexibility, modularity and less environmental concerns such as very low emissions. A FC is a stationary device which uses hydrogen as a fuel to generate power. There are different types of FCs which are classified according to their operating temperature and electrolyte. Among all, the SOFC can accomplish efficiency atleast 50% [6]. Some unique characteristics such as internal reforming, high current density and very fast kinetics reaction in the absence of platinum catalysts make the performance of SOFC superior among all FCs [7], [8]. Despite high efficiency and flexibility, there are some drawbacks in SOFC. One of the major problem for the SOFC system has the slow dynamic behavior during transient situations in demand power. When a SOFC is subjected to a step increase in load, it experiences an instant drop off of the voltage in the I-V curve and takes several seconds to track the load. Besides this, hydrogen starvation can occurs, which affects the overall performance of SOFC. These problems can be solved by using some storage energy system such as a battery or UC with SOFC in hybrid system.

A hybrid system combines different energy sources and storage systems to achieve high efficiency by taking the advantage of each energy source and/or storage device. UC has high power density and its response is very fast during transient power demand. Therefore, an integration of UC and SOFC/PV arrays with hydrogen storage tanks and ELZ can represent the very best hybrid system. In such a proposed hybrid system, the SOFC should be operated under controlled steady-state condition while the UC is providing the demanded power[1]. Without UC, the SOFC system must supply all the power demand, thus oversize and increase the cost of the SOFC power plant.

This paper is arranged as follows. First, Literature review is explained in Section II. Next, section III provides system configuration Section IV provides the modeling and control of system components. Section V describes the DPCA. Conclusion is provided in Section VI.

2. Literature Review

Many FC based hybrid systems are described in the literature. In [1], authors described a hybrid system using SOFC/UC Combination . In [9], [10], the authors suggested that the FC/UC combination is the most effective option for electric vehicle applications A FC with diesel engine based hybrid system is proposed in [11]. However, the use of diesel engine with FC is not an effective one in terms of cost and pollution problems. The dynamic modeling and simulation of hybrid system consisting FC/UC is discussed in [12]. Robust Control of SOFC with UC are explained in [13], [14]. Similarly, the benefits of FC based generations are supported in [15]–[16]. This paper proposes hybrid combination of SOFC/UC/pv arrays with a hydrogen Storage system for a typical domestic load grid connected applications. The proposed model works under simple Dynamic Power Control Algorithm (DPCA). The DPCA supervised the power flow and entire power management for the propose model and control all the energy sources, storage devices and power converters on the basis of dynamic references.

3. System Configuration

Figure 1 describes the architecture of the proposed system which includes of a SOFC stack and photovoltaic arrays as Primary energy sources.

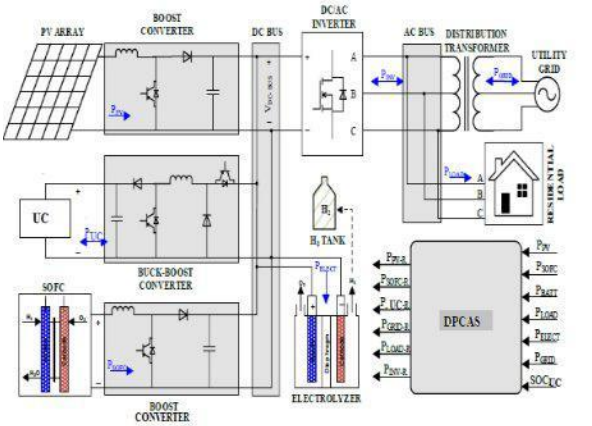

Fig. 1 Architecture of proposed hybrid power system

A UC module is in the proposed structure to utilize as a high power density and/or back energy source. A pressurized alkaline ELZ is integrated as a dump load to produce hydrogen during surplus power which is supplied to hydrogen tanks. The five main subsystems i.e.PV array, SOFC, UC, hydrogen tanks and ELZ are controlled through five separate control systems. All these five system are integrated in parallel to a common DC bus through DC converters. The output of DC bus is synchronized to the grid and/or grid connected domestic load through three phase hysteresis current control inverter.

The proposed system is simulated for a complete one day considering different operating and load conditions. It is important to state that the proposed system is flexible and, therefore, easily expandable as long as a new PV Arrays or SOFC or UC module are added to the existing ones without increasing the circuit complexity. In addition, it is also possible to add another parallel inverter to upgrade the proposed design with high efficiency.

4. Modeling and Control of System Components

This section describes the modeling and power control of system components which are used during simulation of proposed system[1][20].

4.1 Control of PV System

The output power of PV depends upon the atmospheric condition, therefore, to track the maximum power point (MPP) of the PV, a single boost stage is applied to boost the PV voltage. The output current and voltage of the PV are used to compute MPPT error denoted as "e" in figure 2. The MPPT error is calculated using an incremental conductance algorithm. The boost converter is controlled by proportional integral differentiator (PID) controller. The PID controller tries to minimize the MPPT error. The output of PID represents the variation in duty cycle.

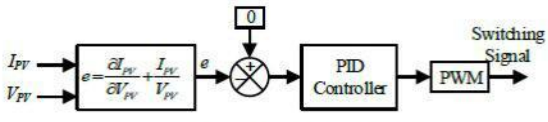

Fig.2 Control diagram of PV system

4.2 SOFC model and control

The model of SOFC is considered in this paper is based on the work described in [17]. There are many operating variables that disturbing the performance of SOFC. For instance, the increase in cell voltage happens with the decreasing in current density and thus increasing the SOFC efficiency. Among all, reactant utilization, U_f, is the most important operating variable, which is the ratio of used fuel (hydrogen) to the total fuel (hydrogen) available [16], and is given as:

$$U_f = \frac{q_{H_2}^{in} - q_{H_2}^{out}}{q_{H_2}^{in}} = \frac{q_{H_2}^{r}}{q_{H_2}^{in}} \qquad (1)$$

where q_{H_2} stands for molar flow of hydrogen. Internally, the SOFC stack consists of several parallel and series small cells. Hydrogen and air (oxygen) are delivered through the cells. The amount of hydrogen fed into the SOFC stack is regulated by adjusting the pressure level and thereby control the real output power of the SOFC system. The SOFC stack average voltage magnitude can be written in equation (2) using the Nernst's equation and Ohm's law.

$$V_{SOFC} = N_o\left(E_o + \frac{RT}{F}\left(\ln\left(\frac{P_{H_2}P_{o_2}^{0.5}}{P_{H_2O}}\right)\right)\right) - rI_{f0} \qquad (2)$$

where N_0 represents the number of cells in series, E0 is the voltage denoting the reaction free energy, R and F are the universal gas constant and Faraday's constant, respectively stands for temperature while the If denotes the current of the SOFC stack P_{H2} P_O,and P_{H2O} are the partial pressure of hydrogen, oxygen and water, respectively and determined by using equation (3) and its parameters is given in Table 1 [18], [19]

$$\dot{P}_{H_2} = \frac{1}{t_{H_2}}\left(P_{H_2} + \frac{1}{K_{H_2}}\left(q_{H_2}^{in} - 2K_r I_{SOFC}\right)\right)$$

$$\dot{P}_{H_2O} = \frac{1}{t_{H_2O}}\left(P_{H_2O} + \frac{1}{K_{H_2O}} - K_r I_{SOFC}\right)$$

$$\dot{P}_{O_2} = \frac{1}{t_{O_2}}\left(P_{O_2} + \frac{1}{K_{O_2}}\left(q_{o_2}^{in} - K_r I_{SOFC}\right)\right) \qquad (3)$$

Where q_{H2}^{in} and $q_{o2}i^{n}$ stands for molar flow of hydrogen and oxygen, respectively and K_r is a constant which is described in equation (4) by the relation between the SOFC current and the rate of reactant hydrogen.

$$q_{H_2}^{r} = 2K_r I_{SOFC} \qquad (4)$$

Table 1. SOFC Parameters

Name	Value
Faraday's constant (F)	96484600 [C/kmol]
Hydrogen valve constant (K_{H_2})	422 × 10–5 [kmol(s atm)]
K_r constant = N_o/4F	2.2802 × 10^{-7} [kmol/(sA)]
No of cells in series (N_o)	88
FC Internal Resistance (R)	0.00303 (Ω)
FC absolute temperature (T)	343 [K]
Universal gas constant ®	8314.47 [J/kmol/K)]
Oxygen valve constant (K_{O_2})	2.11 × 10^{-5} [kmol/(s atm)]
Water valve constant (K_{H_2}O)	7.716 × 10^{-6} [kmol/(s atm)]

The output power of SOFC is determined using equation (5)

$$P_{SOFC} = V_{SOFC}\, I_{SOFC} \qquad (5)$$

To take full benefit from SOFC system, it is necessary to design a proper control system for it. In this research work, the Output voltage of SOFC is first boosted via boost converter [20]. The boost converter is controlled through Proportional Integral Differentiator (PID) controller. The reference voltage is determined using reference power defined by DPCA. The PID produces suitable output based on the error of a reference and determines the actual voltages. The PWM generator translates the output into a square wave pulse of corresponding duty cycle. The control scheme of SOFC system is depicted in Figure 3.

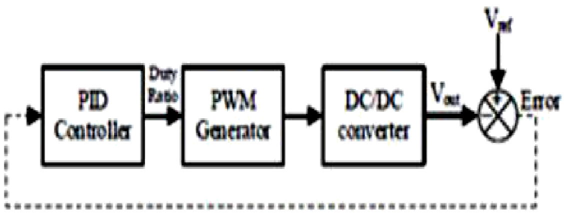

Fig.3 Control strategy of SOFC/EL2 system

4.3 ELZ Model and Control

The production of hydrogen and oxygen from water via electrolysis occurs in an apparatus called an ELZ. The chemical reaction of water electrolysis is written as

$$H_2O_{(L)} + electrical\ energy \Rightarrow H_{2(G)} + \frac{1}{2}O_2 \qquad (6)$$

Using Faraday's law, the production of hydrogen gas (n_{H2}) is directly proportional to the ELZ current (i_{ELZ}) and is written in equation (7), [21]

$$n_{H_2} = \frac{\eta_F \eta_C i_{ELZ}}{2F} \qquad (7)$$

where η_c and η_F represents the number of ELZ cells in series and faraday efficiency, respectively. The ratio of real and the theoretical maximum amount of hydrogen generated in the ELZ is known as Faraday's efficiency. In general, it is assumed to be more than 99% and is given by [19]

$$\eta_F = 96.5e^{(0.09/i_{ELE} - 75.5/i_{ELE}^2)} \qquad (8)$$

In order to control the power flow in the ELZ, the input current needs to be controlled. A buck converter is used to control the power flow in the ELZ by regulating the ELZ current[22]. Figure 2 shows the control scheme of ELZ with V_{ref} and V_{out} are replaced by I_{ref} and I_{out}, respectively.

4.4 Hydrogen Tank Model

ELZ sends the required amount of hydrogen to the SOFC and the remaining hydrogen is sent to the hydrogen storage system called the hydrogen tank, whose system dynamics can be expressed as [23]

$$P_t = z\frac{N_{H_2} R T_t}{M_{H_2} V_t} + P_a \qquad (9)$$

where P_t is the pressure of the tank, z is the compressibility factor, R is the universal gas constant, V_t is the volume of the tank, T_t is the operating temperature, P_{ti} is the initial pressure of the tank, and NH2 and MH2 stands for hydrogen moles per second passed to the tank and the molar mass of hydrogen gas, respectively.

4.5 UC Model and Control

This study follows the classical UC model depicted in Figure 4, which consists of two resistances, i.e., an equivalent parallel leakage resistance (R_P), and an equivalent charging/discharging series resistance (R_S) and double-layer capacitance (C) [24], [25]. The amount of energy consumed/drawn (EUC) from the UC bank is directly proportional to the capacitance and the difference in the initial (V_{in}) and the final value (V_{final}) of the UC voltages and is written as:

$$E_{UC} = \frac{1}{2}C(V_{in}^2 - V_{final}^2) \qquad (10)$$

The effective prescribed energy for a specific load can be provided by various UC bank arrangement. In real applications, the required amount of terminal voltage and energy or the capacitance of UC storage system can be supplied using multiple UCs in series The control system for

UC depends on the basis of their charging and discharging capabilities. The output voltage or power of UC is always smaller than the DC bus voltage. A boost converter is used to boost the output voltage of UC to the required value i.e., 700V. Similarly, a buck converter is used to charge the UC from DC bus through DPCA. Furthermore, the buck-boost converter is itself controlled by PID controller. Due to inner control loops, SC must follow (15). The control system for UC is depicted in Figure 4.

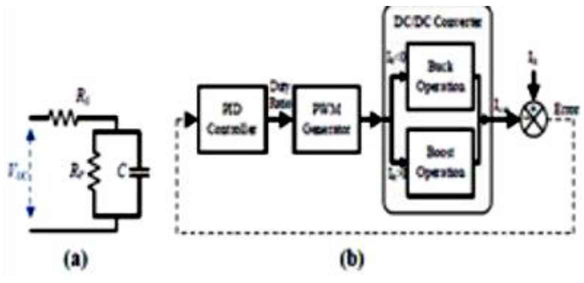

Fig.4 UC system (a) Model of UC (b) Control system of DC-DC converter

where I^*_{UC} is reference current, and P^*_{UC},V^*_{UC} are the reference power and reference voltage, respectively.

4.6 Grid Connected Inverter Control and Synchronization

It is essential that the output of DC bus is synchronized t the grid or grid-integrated load through three phase inverter. In this study, the inverter is controlled using two Proportional Integral (PI) controllers based on hysteresis current control technique. The hysteresis current control technique is one of the simplest method to implement and has robust current control characteristics against load [26].

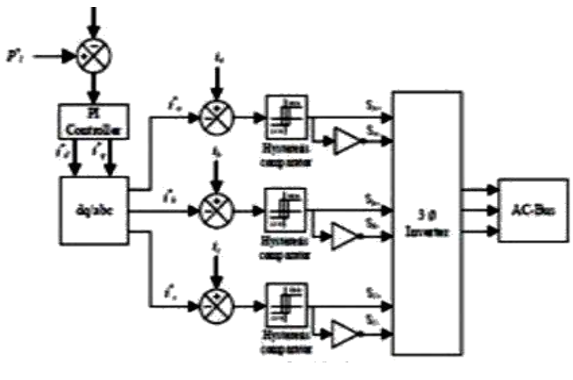

Fig.5 Control scheme of main inverter system

The proposed technique compares the actual and reference powers. Using dq/abc transformation, the abc reference currents are produced. The reference currents and the actual currents are compared. Furthermore, the error signal (current) is fed to a hysteresis current controller based on PI controllers which delivers a set of proper signals to the PWM signal generator. It is important that the injected inverter current must be synchronized with grid voltage and has unity power factor. In this regard, instantaneous phase angle and frequency of a grid voltage are the two important parameters to synchronize the system with grid and/or integrated load [27]. Furthermore, the phase angle calculated through phase locked loop. The estimated phase angle is then used to synchronize the system with the grid. The control strategy is shown in Figure 5.

5. DPCAS of Proposed HPS

To supply uninterruptable power supply to load, a proper management system is required to be established. In this research, the DPCA based management system is developed.

The primary goal of DPCA system is to ensure uninterruptable power to the load by using all available energy sources. The secondary goal of DPCA system is to keep the system stability parameters in the acceptable limits, prevents it from blackouts and keeps the system synchronized with Local Grid Station (LGS). The DPCA manages the power flow based on seven basic inputs i.e., PV array output power(P_{PV}),SOFC output power (P_{SOFC}), Residential load demand (P_{RL}), Local grid output power (P_{LGS}), ELZ power consumption (P_{ELZ}), Output power and state of charge of UC (P_{UC}, T_{UC}).Based on the above inputs, the DPCA generates references to all energy sources and converters.

The operating strategies employed in the DPCA are as follows:

The use of power generated by the PV system has the priority in meeting load demand over that delivered by the SOFC system or by the UC.

If the power generated by PV system is higher than the demand, the excess power will be used to charge the UC.

If still excess power is available, then it will be sent to ELZ to produce hydrogen for SOFC.

Similarly, if the total power generated by the PV system is less than the demand, power will be delivered from the SOFC.

If the load demand exceeds the power generated by the PV/SOFC combination, the difference is supplied by the UC. Based on the above key steps and energy flow, the operation of DPCA system is characterized into three different operating states, For explanation of algorithm shown in figure 6, it is better to divide the operation of DPCA into several modes. Mode I: PV disconnected SOFC disconnected UC discharging (PDSDUD), Mode PV disconnected SOFC connected UC discharging (PDSCUD), Mode III: PV connected SOFC disconnected UC charging (PCSDUC), Mode IV: PV connected SOFC disconnected UC disconnected (PCSDUD).

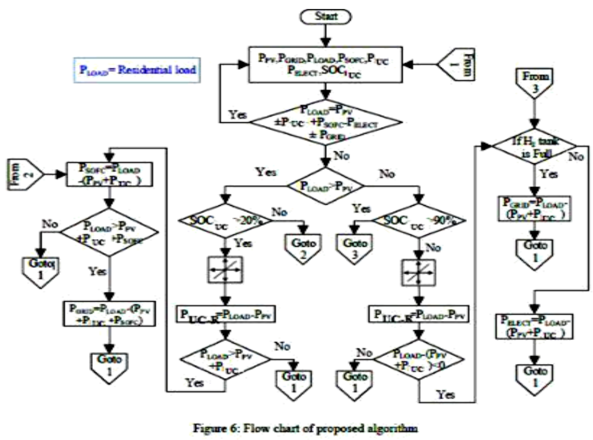

Fig.6 Flow chart of proposed algorithm

Mode I: PDSDUD

In this operating mode, the power generated by PV is zero due to low irradiance or bad weather i.e., PPV < PLOAD. Thus, the need of UC and SOFC is essential. The DPCA checks the UC SOC and if sufficient charge is available, DPCA controls the buck-boost converter to deliver its maximum power and applying a reference PUC-R = PLOAD - PPV as shown in figure 6. Hence all the power demand is provided by the UC itself.

Mode II: PDSCUD

This mode is similar to the mode I, but the difference in both modes is the involvement of SOFC which is absent in mode I. Alike mode I, the PV and UC goes in same fashion. As the power demand is not satisfied with the UC alone, so, SOFC is acting as an active player in this mode. The remaining power demand reference is given to the boost converter of SOFC by DPCA which is PSOFC-R = PLOAD - PPV – PUC as shown in figure 6.

Mode III: PCSDUC

This mode is applicable when PV is generating excess power i.e., PPV > PLOAD. So in this mode, there is no need of SOFC. The excess power generated by PV system is sent to the UC with reference power PUC-R = PPV - PLOAD as shown in figure 6. The electrolyzer will consume any excess power present inside the system. Here, there are two conditions for excess power (a) when UC is charging on its maximum power remaining excess power is still inside the system (b) the UC is fully charged and then the remaining power exists inside the system. From the above two conditions, the first condition is incorporated in this mode while the second condition will be employed in next mode. Hence, in this mode, the UC is charging with its maximum power and remaining power is consumed by the electrolyzer as shown in fig 6.

Mode IV: PCSDUD

In this operating mode, the PV is generating power greater than the load demand. Therefore, the excess power is sent to UC or electrolyzer depending upon the status of the state of charge (SOC) of UC i.e., $SOC_{UC} < 90\%$ and tank pressure. If the SOC of the UC reaches its maximum value, the second condition (discussed in previous mode) is fulfilled

6. Conclusion

A small PV Array /SOFC hybrid system with UC and hydrogen storage system for grid-on and grid-off applications is proposed in this paper. The drawback of single energy source i.e., SOFC is described which is then overcome by a high power density device called UC. Dynamic modeling, power control, integration of all individual system components and then synchronization of DC link with grid is described. The overall power flow and energy management of the proposed hybrid model is managed by designing a classical based dynamic power control algorithm. The performance of the proposed model is tested through different load conditions for the complete one day. MATLAB/Simulink results confirm the validity of the model in terms of voltage regulation, power quality, system stability and dynamic characteristics.

References

1. Syed Zulqadar Hassan,Hui Li, Tariq Kamal, Sidra Mumtaz, Laiq Khan (2016), “Fuelcell/ Electrolyzer /Ultra-capacitor Hybrid Power system: F Focus on Integration, Power Control and Grid Synchronization”, Proc. of IEEE Interntional Conference on Applied Sciences and Technology, DOI: 10.1109/IBCAST.2016.7429882
2. K.-S. Ro and S. Rahman (1998), “Two-loop controller for maximizing performance of a grid-connected photovoltaic-fuel cell hybrid power plant,” IEEE Transactions on Energy Conversion, Vol. 13, No. 3, pp. 276–281.
3. Y. Sukamongkol, S. Chungpaibulpatana and W. Ongsakul (2002), “A simulation model for predicting the performance of a solar photovoltaic system with alternating current loads,” Renewable Energy, Vol. 27, No. 2, pp. 237–258.
4. J. J. Hwang, D. Y. Wang, N. C. Shih, D. Y. Lai, and C. K. Chen (2004),“Development of fuel-cell-powered electric bicycle,” Journal of Power Sources, Vol. 133, No. 2, pp. 223–228.
5. J. J. Hwang, W. R. Chang, F. B. Weng, A. Su, and C. K. Chen (2008), “Development of a small vehicular PEM fuel cell system,” International Journal of Hydrogen Energy, Vol. 33, No. 14, pp. 3801–3807.
6. P. Costamagna, L. Magistri, and A. F. Massardo (2001), “Design and part-load performance of a hybrid system based on a solid oxide fuel cell reactor and a micro gas turbine,” J. Pow. Sources, Vol. 96, No. 2, pp. 352-368.
7. M. H. Nehrir and C. Wang (2009), Modeling and Control of Fuel Cells: Distributed Generation Applications, Wiley-IEEE Press.
8. Chithra JK, Panneerselvam M, Prakasam P (2014), “Mitigation of Fault Current Level using Super Conducting Fault Current Limiter in Wind Turbine Generation Systems,” International Journal of Scientific & Engineering Research, Vol. 5, No. 4, pp. 40-46.
9. P. Rodatz, G. Paganelli, a. Sciarretta, and L. Guzzella (2005), “Optimal power management of an experimental fuel cell/supercapacitor- powered hybrid vehicle,” Control Eng. Pract., Vol. 13, No. 1, pp. 41–53.
10. V. Paladini, T. Donateo, A. de Risi, and D. Laforgia (2007), “Super-capacitors fuel-cell hybrid electric vehicle optimization and control strategy development,” Energy Convers. Manag., Vol. 48, No. 11, pp. 3001–3008.
11. Panneer Selvam M, Prakasam P (2016), “Small Signal Stability Analysis of DFIG Fed Wind Power System Using a Robust Fuzzy Logic Controller,” Circuits and Systems, Vol. 7, No. 4, pp. 390-401.
12. T. Senjyu, T. Nakaji, K. Uezato, and T. Funabashi (2005), “A Hybrid Power System Using Alternative Energy Facilities in Isolated Island,” IEEE Trans. Energy Convers., Vol. 20, No. 2, pp. 406–414.
13. M. Uzunoglu and M. S. Alam (2007), “Dynamic modeling, design and simulation of a PEM fuel cell/ultra-capacitor hybrid system for vehicular applications,” Energy Convers. Manag., Vol. 48, No. 5, pp. 1544–1553.
14. T. Das and S. Snyder (2011), “Adaptive Control of a Solid Oxide Fuel Cell Ultra-Capacitor Hybrid System,” IEEE Transactions on Control Systems Technology, Vol. 21, No.2, pp. 372–383.

15. T. Allag and T. Das (2012), "Robust control of solid oxide fuel cell ultracapacitor hybrid system," Control Syst. Technol. IEEE, Vol. 20, No.1, pp. 1–10. .
16. K. Rajashekara (2005), "Hybrid fuel-cell strategies for clean power generation," IEEE Trans. Ind. Appl., Vol. 41, No. 3, pp. 682–689.
17. H. Liang, J. Li, W. Zhang, and X. Zhu (2012), "Research on Full-process Model of Fuel Cell Generation System," Proc. of IEEE International Conference on Power System Technology, pp. 1–5.
18. H. Lihua (2005), "Analysis of Fuel Cell Generation System Application," Ph.D Thesis, Chongqing University.
19. X. Shisen, Cheng Jian (2005), Fuel Cell Power Generation System, Beijing: China Electrical Power Press.
20. Hajizadeh and M.A. Golkar (2012), "Control of hybrid fuel cell/energy storage distributed generation system against voltage sag," I. J. Elec. Pow. & Energy Syst., Vol. 32, No. 5, pp. 488-497.
21. M. Uzunoglu and M. S. Alam (2006), "Dynamic modeling, design, and simulation of a combined PEM fuel cell and ultra capacitor system for stand-alone residential applications," IEEE Trans. Energy Convers., Vol. 21, No. 3, pp. 767– 775.
22. S. Z. Hassan, T. Kamal, S. Mumtaz, and L. Khan (2015), "Performance of Grid-Integrated Photovoltaic/Fuel Cell/ Electrolyzer/Battery Hybrid Power System," Proc. of 2nd International Conference on Power Generation Systems and Renewable Energy Technologies, DOI : 10.1109/PGSRET.2015.7312249.
23. T. Lajnef, S. Abid, and A. Ammous (2013), "Modeling, control, and simulation of a solar hydrogen/fuel cell hybrid energy system for grid-connected applications," Adv. Power Electron., Vol. 2013, pp. 1–9.
24. K. Sapru, N. T. Stetson, S. R. Ovshinsky, J. Yang, G. Fritz, M. Fairlie, and a. T. B. Stuart (1997), "Development of a small scale hydrogen production storage system of hydrogen applications," IECEC-97 Proc. Thirty- Second Intersoc. Energy Convers. Eng. Conf., Vol. 3, pp. 1947–1952.
25. A. Osman Haruni, M. Negnevitsky, M. E. Haque, and A. Gargoom (2013), "A novel operation and control strategy for a standalone hybrid renewable power system," IEEE Trans. Susta. Ener., Vol. 4, No. 2, pp. 402-413.
26. O. C. Onar, M. Uzunoglu, and M. S. Alam (2008), "Modeling, control and simulation of an autonomous wind turbine/photovoltaic/fuel cell/ultracapacitor hybrid power system," J. Power Sources, Vol. 185, No. 2, pp. 1273–1283.
27. R. L. Spyker and R. M. Nelms (2000), "Analysis of double-layer capacitors supplying constant power loads," IEEE Trans. Aerosp. Electron. Syst., Vol. 36, No. 4, pp. 1439–1443.
28. N. A. Rahim and J. Selvaraj (2007), "Implementation of Hysteresis Current Control for Single-Phase Grid Connected Inverter," 2007 IEEE Int. Symp. Ind. Electron., pp. 572– 577.
29. V. Kaura,VikramBlasko (1997), "Operation Of Phase Locked Loop Under Distorted Utility Conditions," IEEE *Trans. Ind. Appl.*, Vol. 33, No. 1, pp. 58–63.

