Hybrid Power System for Domestic Applications - A Review

M.P.Dakhare[1]; M.W.Thakare[2]; V.D.Thakur[3]
Department of Mechanical Engineering, Govt.Polytechnic, Amravati, India
mpdakhare@gmail.com [1]; manoj.thakare966@gmail.com [2]; vdthakur2000@gmail.com [3]

***Abstract:** Various aspects of solar hydrogen fuel cell have been discussed in this paper with a focus on the use of hydrogen produced during electrolysis process towards developing a hybrid system for domestic applications. The combination of solar energy and hydrogen fuel cell in the proposed system is aimed at delivering uninterrupted power to common domestic appliances. The performance of fuel cell will be analyzed by controlling pressure, temperature and humidity of hydrogen gas used in the system.*
***Keywords:** Electrolysis; hydrogen; fuel cell; hybrid power system.*

1. Introduction

The main source being used to produce energy today is the fossil fuels. They are not only being depleted rapidly but are also polluting the environment and affecting our economical stability. With continuous escalation in oil prices to levels that threaten our economy, alternate energy is starting to play an important role in our society. Need has been felt for long to develop alternate sources of energy and relentless efforts are being made all over the world to find reliable and non pollutant ways of producing energy. Amongst different approaches, hydrogen fuel cell and solar panels appear to be the most viable and promising alternatives. Hydrogen is available in abundance, has cleaner emissions and greater efficiency than that of oil. Solar hydrogen fuel cell systems when integrated together present a new approach that promises clean and friendly energy production. Solar fuel cell based hybrid system for power generation uses hydrogen and oxygen to convert chemical energy into electrical energy. This paper focuses on the combination of solar fuel cell based hybrid system for power generation and reviews the developments so far.

2. Hybrid Power System

Amongst various types of fuel cell systems, proton exchange membrane fuel cell power generation system has been found to be suitable especially for hybrid energy systems with higher power density and lower operating temperature. Different aspects of electrolysis and fuel cell system operation have been reported in published literature [1, 2].

2.1 Water Electrolysis

Electrolysis is an electrochemical process in which electrical energy is the driving force of chemical reactions. For electrolysis, an acidic water solution was favored by earlier investigators. Now a day, however, alkaline electrolytes such as potassium hydroxide (KOH) is used because it offers the advantage of using materials which are cheaper and less susceptible to corrosion. Electrolysis plants with normal or slightly elevated pressure usually operate at electrolyte temperature of 70-90^{o}C, cell voltage of 1.85-2.05 V and consume 4.5 Kwh/m^3 of hydrogen. The efficiency of electrolysis can be increased by increasing process temperature because it lowers the voltage required to electrolyze water[3].The efficiency of electrolysis will be increased by providing stirrer action in the electrolyte.

ISSN (ONLINE): 2321-3051
Vol.8 Issue.2,
Feb 2020
Pg: 1-8

Energy(Electricity) + $2H_2o \rightarrow 2\ H_2 + O_2$

The use of electro catalyst consisting of hydrogen storage alloys, such as Ti_2Ni alloy and nickel molybdenum coatings is reported in [4]. The electro-catalytic activity for hydrogen evolution increases with increase in molybdenum content and is dominated by electrode surface composition. The hydrogen storage alloys inside the electrodes mainly serve the functions of enhancing corrosion resistance against power interruptions through electrochemically releasing absorbed hydrogen. The hydrogen storage alloys absorb hydrogen in electrolysis process and release the absorbed hydrogen during intermittent operation through a series of electrochemical reactions. The new electro catalyst shows excellent stability under intermittent operation as well as continuous electrolysis. The efficiency of electro catalyst can be increased by using platinum coated electrode and by varying temperature of water because some of the energy will be supplied as heat which is cheaper than electricity [4].

Platinum / carbon is used for cathode. The major problem associated with low temperature electrolysis is the high electric energy consumption which can degrade the competitiveness of the process. Although low temperature is a mature technology, high temperature electrolysis presents a greater potential as the electrolysis of water is increasingly endothermic with increase of temperature. The required electric power is reduced at higher temperature. Another advantage of high temperature is the reduction of over potentials which cause power losses in the electrolysis cell.

A micro reactor for hydrogen generation from sodium borohydride was designed and fabricated by T. Kim [5]. The cobalt supported on the nickel form was selected as catalyst for the hydrolysis of the sodium borohydride. The hydrogen generation rate was 50 ml/min at temperature of 30^0C.The generated hydrogen was supplied to a micro fuel cell and maximum power output was 157 mW at the current of 0.5A. [5]

In [6] a systematic approach for investigation of hydrogen fuel cell hybrid electric vehicle was considered. The approach involves developing a mathematical model incorporating renewable hydrogen production, storage and refueling of the fuel cell vehicle system. A HFCV system model has been developed for simulation study for better energy management strategies. This model can be used for math based vehicle developments and controller design to improve system performance.

The generation of hydrogen can be measured easily by trapping the hydrogen gas produced and determining its volume. This is done by connecting the reaction vessel to a tank filled with water such that the water gets pushed out as hydrogen fills the tank. Using the arrangement shown in Fig1, one can determine the volume of hydrogen gas produced in terms of the volume of the displaced water using graduated cylinder. Hydrogen generation rate can also be increased by providing stirrer in reaction vessel.

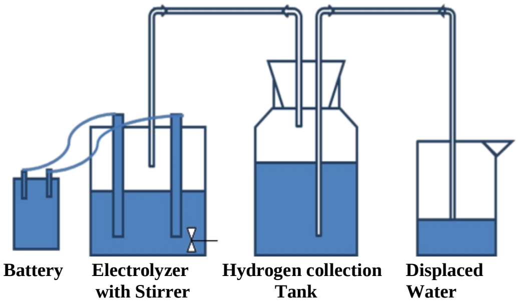

Figure 1

2.2 Fuel Cell

A fuel cell operates like a battery. It does not run down or require recharging and produces energy in the form of electricity and heat as long as fuel is available. The fuel cell converts chemical energy directly into electricity without combustion by combining oxygen from the air with hydrogen gas. It produces electricity so long as fuel, in the form of hydrogen, is supplied. No pollutants are produced.

A fuel cell is a device that generates electricity and heat by converting the energy of the chemical reaction between fuel and an oxidant. Fuel cells are more energy efficient than combustion engines and the hydrogen used to power them can be obtained from a variety of sources. If pure hydrogen is used as fuel, a fuel cell emits only heat and water, eliminating concerns about air pollutants or green house gases.

Fuel cell consists of an anode, cathode catalyst and an electrolyte and works by catalyst, separating the electrons and protons of the reactant fuel (at the anode) and forcing the electrons to travel through a circuit and thus generate electric power. At cathode, another catalytic process takes the electrons back in, combines them with the protons which have travelled across the electrolyte and to oxidant, to form waste products. Fuel cells are combined in series into groups called stacks to obtain a usable voltage and power output. The stacks increase the amount of electricity generated. The amount of power produced by a fuel cell depends on several factors including fuel cell type, cell size, temperature at which it operates and the pressure at which gases are supplied to the cell. A single fuel cell produces less than 1.16 volts barely enough for even the smallest applications [7, 8].

In many fuel cells, the fuel is hydrogen and oxidant is oxygen. Different types of fuel cells used are:

1) Proton exchange membrane (PEM)
2) Solid oxide fuel cell (SOFC)
3) Alkaline fuel cell (AFC)
4) Phosphoric acid fuel cell (PAFC)
5) Direct methanol fuel cell (DMFC)
6) Molten carbonate fuel cell (MCFC)

Most of these were found well suited for many applications including automobiles, buildings and for smaller applications. Compared to other fuel cells, proton exchange membrane fuel cell operates at low temperature with higher efficiency. The efficiency of proton exchange membrane fuel cell is increased by using solid electrolyte catalyst such as platinum. PEM fuel cells have gained international attention as an option for alternative automotive and stationary power owing to features such as adaptable size and low operating temperature. The electrolyte PEMFC is a polymer membrane/film. The operating temperature is in the range of 80-100^{o}C. The use of a solid polymer electrolyte eliminates the need of a water tight compartment for the liquid electrolyte and the corrosion and safety concerns associated with it.

Flow plates used in a fuel cell performs several important functions:

1) Channelize H_2 and O_2 to the electrode.
2) Channelize water and heat away from fuel cell.
3) Conduct electrons from the anode to the electrical circuit and from the circuit back to the cathode.

Hydrogen fuel cell H_2 is channeled to the anode where catalyst separates the hydrogen negatively charged electrons from positively charged protons.

$$2H_2 \longrightarrow 4H^+ + 4e^-$$

Membrane allows the positively charged protons to pass through the cathode, but not negatively charged electrons.

Negatively charged electrons must flow around the membrane through an external circuit. This flow of electrons forms an electrical current.

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

At cathode negatively charged electrons and positively charged protons hydrogen protons combine with oxygen to form water and heat [20].

Hydrogen energy and fuel cells were investigated and application areas of fuel cell systems were researched by Gencoglu and Ural [7]. The design of fuel cell system was achieved and the components of the system were defined for the residential application areas of fuel cell system.

3. Hybrid Systems

For regions where plenty of solar radiation is available, as in the plains of Indian subcontinent, use of solar energy to power a greenhouse provides a viable option. The solar energy can be harnessed by mounting solar photovoltaic modules on roof of the greenhouse. But as solar energy is not available at night or may be insufficient to generate the required electrical energy to operate a greenhouse round the year, some form of power back up arrangement is necessary. The most common type of power back-up arrangement that is used at present is that of battery despite of the limitations such as short life span, limited storage capacity and problems associated with disposal. These problems can be overcome by using fuel cell back up. Such a system has more benefits compared to battery backup when used with weather dependent power source.

A combination of wind, fuel cell and ultra capacitor for system for sustained power generation is seen in [8]. In this system, simulation of wind, fuel cell and ultra capacitor hybrid power generation system with power flow controllers has been undertaken. When the wind speed is sufficient, wind turbine can meet the load while feeding electrolyzer. If the available power from the wind turbine cannot satisfy the load demands, the ultra capacitor can meet the load demand above the maximum power available from fuel system for short duration. Since the wind speed is not available during all hours the efficiency of wind turbine gets reduced. It thus reduces performance of fuel cell also. This difficulty can be overcome by using solar photovoltaic cell for operating the electrolyzer.

Green house technology is a major breakthrough in the field of agriculture as it gives higher productivity of crops and flowers and also promotes off seasonal cultivation. In order to promote off seasonal cultivation inside green house, an artificial microclimate is required which may be maintained using a suitable heating or cooling system with humidity control depending on the climate. A model of an integrated power generation cum storage system suitable for powering a fan pad ventilated green house has been presented in [9]. Green house can pave the way for sustainable cultivation in self sustained greenhouses even in remote areas where probability of getting conventional grid connected electricity at steady voltage round the year is very low. Even for greenhouses that can be powered through grid connected electricity, problems of low voltage and high power fluctuation are very common and there are frequent power cuts due to loadsheding or breakdowns. Thus, for greenhouse installation in rural areas, the requirement of electricity on a continuous basis imposes a significant restriction, leading to increased cost and reduced operational reliability.

In solar hydrogen fuel cell based hybrid system comprising of PEM electrolyser, fuel cell stacks and compressed gas storage integrated with a fan-pad ventilated greenhouse have been presented. A power management strategy has also been included. Electrical energy is generated in an array of photovoltaic modules mounted on the canopy of a greenhouse. Excess energy after meeting the requirements of the greenhouse during peak sunshine hours, is supplied to an electrolyser bank to generate hydrogen gas, which is compressed and stored in tanks. The same is consumed by PEM fuel cell stacks to meet the load requirement during the deficit hours. The performance of the integrated system for different representative seasons of a year is presented. The most common type of power back up arrangement is battery. The fuel cell back up has more benefits compared to battery backup.

To be able to power residential homes with solar energy and hydrogen fuel cells, combined systems have been investigated using a scaled down model house [9]. This model provided cost effective studies and analysis to estimate systems efficiency, size and capacity necessary to energize an average residential home. It is also very important to establish a reference point by building a small mockup that could eventually help constructing full scale homes, saving money and time. The system consists of solar panels that are connected to the household, and to an electrolyser. When the sun is shining, the solar panels produce electricity that is used to produce hydrogen and to provide energy to a residential home. The energy demanded by the household during the period of sunlight is just a fraction of the total energy needed to run the house twenty four hours per day. Therefore, the remaining solar energy produced in this process will have to be stored for later demand.

It is to be noted that the solar radiation (photons) hits the solar panels, and produces an electrical reaction in the solar cell itself. This energy is utilized to meet the energy demand of a household, and to produce hydrogen. Secondly, if the solar panels system had been designed to meet 100% demand of energy in the household, then the amount of energy produced by the solar panels is not be completely consumed during the period of sunlight and, therefore, the remaining energy must used to produce hydrogen by electrolysis. This hydrogen can be stored in tanks to produce energy using fuel cells. The hydrogen gas is the source of fuel supply to the fuel cell system. The fuel cell system thus produces energy on demand after the sun set without pollution [10].

A comparison between internal combustion engine and hybrid fuel cell rickshaw configuration was done using realistic drive cycle. An ICE and two candidate fuel cell rickshaw models were created and using powerstrain system analysis toolkit (PSAT) software [11].

The future hydrogen energy utilization patterns have been presented for better environment and sustainable development [12]. The efficiency of electrolysis will be increased by increasing process temperature by using platinum coated electrode and using stirrer in vessel. Wind energy is used for electrolysis. The wind speed is not available during all 24 hours, and this as a consequence, reduces the performance of fuel cell. Due to frequent power cuts, the requirement of electricity on continuous basis imposes a significant restriction, leading to increased cost and operational reliability. Fuel cell backup has more benefits compared to battery backup. Solar hydrogen fuel cell systems when integrated together represent a new approach that promises clean and friendly energy production.

In [13]a fuel cell hybrid electric vehicle the fuel cell stack is assisted by one or more energy storage devices are the battery and ultra capacitor. In this paper 10 different configurations of the fuel cell, battery and /or ultra capacitor is investigated and compared. The method is based on simulation of the power flow through the propulsion system and a proposed strategy for dividing the power between fuel cell and energy storage devices.

When current is drawn from fuel cell, it is critical that the reacted oxygen is replenished rapidly by air supply system to avoid stack starvation and damages. There is a lack of control authority in avoiding excessive oxygen starvation during high current demand. To maintain efficiency and avoid degradation of available fuel cell voltage a control system is necessary for maintaining optimal temperature, membrane humidity and pressure of reactants across the membrane. The design and optimization of the fuel cell auxiliary system is complex because of the interaction between all the performance variables and varying operating conditions. The supply of oxygen is to the cathode is one of the key factors in operation of fuel cell stack. When current is drawn from a fuel cell, the air supply system should replace the reacted oxygen. Otherwise the cathode will suffer from oxygen starvation which damages the stack and limits the power response of the fuel cell. In high pressure fuel cells a compressor motor is used to provide that oxygen reacts instantaneously as current is drawn from the stack, while the air supply rate is limited by the manifold dynamics and compressor operational constraints.[14]

A review and analysis of a fuel cell system modelling and controller design for electric fuel cell vehicle applications. This paper presents principal of fuel cell dynamics. The work proceeds to investigate the fuel cell models and techniques that have been applied to develop control law for fuel cell systems.[16]

In [17] fuel cell will make a valuable contribution to future power generation facilities. They improve the flexibility and increase the options for many applications, such as distributed power, vehicle propulsion and portable devices. Their main property is the high electrical efficiency compared to other energy conversion devices. Both the low temperature and high temperature fuel cell have their advantages and disadvantages depending on the application.

In [18] a neural network predictive controller have been designed to control the output voltage of fuel cell with varying load and at the presence of fluctuations and reduction of noise and fluctuation effects. The dynamic electrochemical model of PEMFC was expressed and used to generate data with current and partial pressure of hydrogen as input and voltage as output. Simulation result indicates that performance of neural network predictive controller is better than PID and its accuracy and speed of convergence is more. This controller can reduce effect of noise by an adoptive filter.

In [19] a novel multipurpose portable PEM fuel cell solar battery system was custom designed, constructed and laboratory tested, specially aims for applications in the rural areas remote from conventional electric power grid. The various power sources namely solar cell, battery and PEM fuel cells can combine harmoniously to obtain higher power voltage, whilst maintaining their individual advantages such as good startup performance. The maximum power of the PEM fuel cell /solar/battery with load is in the range of 2.4W-2.7W which can maintain continuously. Apart from good cold start characteristic, the portable system also exhibits stable voltage, compact in size and acceptable in weight, hence suitable for rural power application at places remote from conventional grid.

In [20] experimental data on the performance of a proton exchange membrane fuel cell with 4-serpentine flow channels. The experiments concentrate on the effects of hydrogen flow rate, anode humidification of temperature and oxygen flow rate. The experimental results are presented in the form of polarization curves. The result show that the performance is increased with increased with increase in flow rates of hydrogen and oxygen, decreased with increase in anode humidification temperature.

In [21] a pseudo homogeneous model of proton exchange membrane fuel cell for cathode catalyst layer has been proposed and described in details. This model has been solved by Matlab software. It is desirable to achieve higher current densities, lower over potential and lower catalyst consumption. In this regard, some of the design parameters such as over potential, proton conductivity, catalyst layer porosity and catalyst surface area on the performance of fuel cell have been studied.

In[22] Water management in proton exchange membrane fuel cells with particular focus on the issue of water flooding, its diagnosis and mitigation.PEM fuel cell performance is adversely affected by water generation rate at cathode, electro- osmosis drag and the ORR, exceeds liquid water removal rate from the cathode by back diffusion to the anode, evaporation, water vapour diffusion and liquid water capillary transport through the GDL. Flooding in the cathode impedes oxygen transport to reaction sites and serves effectively to block the surface area of the catalysts. Water transport and management in PEM fuel cells depends on several variables, such as the structure and properties of the cell components and the operating conditions, of which the reactant stream humidification, flow field layout and structural and wetting properties of the GDM and MPL are important. Future approaches should focus on the following areas i) development of high temperature PEM fuel cells that can avoid water flooding, due to absence of liquid water at operating temperature above 100^{o}C (ii) innovative CCL design, such as a thinner catalyst layer for easier water removal and optimization of the CCL through, for example, structural and hydrophobicity modifications.(iii) new material development, such as a thinner but stronger membrane that not only facilitates easy water removal through the membrane but also improves the reliability of the thon membrane and (iv) a greater understanding of the fundamental processes of water management and flooding through modelling, especially of the role of the CCL.

In [23] the effects of different operating parameters on the performance of proton exchange membrane fuel cell have been studied experimentally using pure hydrogen on the anode side and air on the cathode side. Experiments with different fuel cell operating temperatures, different cathode and anode humidification temperature, different operating pressure and various combinations of these parameters have been carried out. The experimental results are presented in the form of polarization curves which show the effect of various operating parameters on the performance of the PEM fuel cell.

In [24] the effects of different operating parameters on the proton exchange membrane 4-serpentine flow channel fuel cell have been studied theoretically by modelling the problem in fluent. Computer simulation results are obtained for voltage as a function of current density at different cell temperature, operating pressure, different humilities, gas diffusion layer thickness and catalyst layer thickness. The simulation results are compared with experimental data.

Fig 2 shows a schematic diagram of the solar hydrogen fuel cell based hybrid system. In this system, performance of fuel cell is enhanced by water management in the membrane. Membranes in PEM fuel cells are water filled to keep the conductivity high. A dry out membrane possesses a lower conductivity for proton exchange. One way of improving water management is to humidify the gases coming into the fuel cell. Another form of water management can be found in direct hydration of the membrane by mounting porous fibre wicks. The performance of the fuel cell can be analyzed by varying pressure, temperature and humidity of the membrane.

4. Conclusions:

The discussion above was mainly focused on production of electricity from fuel cell based hybrid power system in which fuel is in the form of hydrogen. More importantly, this abundant source of energy is pollution free. The findings suggest the use of electrolysis and fuel cell for developing efficient hybrid power systems. It is readily seen that the huge potential of feely available hydrogen can be harnessed effectively. Its use in fuel cell based hybrid system can significantly help us conserve energy both in urban and rural areas. It is evident that there is urgent need of designing reliable and cost effective hybrid power system for domestic applications, especially in rural areas. Performance of fuel cell would be improved with increase in humidity of the hydrogen and oxygen gas which flows in fuel cell.

References:

1. Emmanuel Zoulias, Elli Varkaraki, Nicolaos Lymberopoulos, Christodoulos N. Christodoulou and George N. Karagiorgis, “A Review on Water Electrolysis”.
2. Muhsin Tunay Gencoglu and Zehra Ural International journal of hydrogen energy 34 (2009) 5242 – 5248, “Design of a PEM fuel cell System for residential application” International journal of hydrogen energy34 (2009)5242-5248.
3. Walt Pyle, Jim Healy, Reynaldo Cortez, “Solar Hydrogen Production by Electrolysis”.
4. Weikang Hu, “Electrocatalytic properties of new electrocatalysts for hydrogen evolution in alkaline water

electrolysis" International journal of hydrogen energy25 2000)111-118.

5. T. Kim Department of Aerospace Engg., Chosun University, South Korea, "Micro reactor for hydrogen generation from sodium Borohydride".
6. Jonathan Williams, Giuliano Premier, Alan Guwy, "Design and Implementation of Renewable Hydrogen Fuel Cell Vehicles".
7. O.C. Onar, M. Uzunoglu, M.S. Alam, "Dynamic Modeling, design and simulation of a wind/fuel cell/ultra-capacitor power generation system" Journal of power Sources 161(2006)707-722.
8. A. Ganguly & S. Ghosh,"Concept and design of a stand-alone solar-powered greenhouse for sustainable cultivation".
9. Hazem Tawfik and Devender Mahajan, "The solar Hydrogen Home".
10. Mohammed Abu Mallouh, "A study of Fuel cell Hybrid Auto Rickshaws Using Realistic Urban Drive Cycles," Jordon Journal of Mechanical and Industrial Engineering vol.4 Jan2010 pages225-229.
11. Ibrahim Dincer, "Hydrogen and fuel cell Technologies for sustainable future" Jordon Journal of Mechanical and Industrial Engineering vol.2 JanMarch2008 pages 1-14.
12. D.L.Yu and J. B Gomm," Polymer electrolyte membrane fuel cell control with feed forward and feedback strategy " International Journal of Engineering science and Technology Vol.2,No.10,2010,pp,56-66.
13. Erik Schaltz peter Omand Rasmussen, "Design and comparison of power systems for a fuel cell Hybrid Electric Vehicle".
14. Ardalan Vahidi, Anna Stefanopoulou Huei Peng," Model for predictive control for starvation prevention in a Hybrid Fuel cell system" Proceeding of the 2004 American Control Conference Boston, Massachusetts June 30-July2,2004.
15. Scott Samuelsen, "Fuel cell/ gas turbine Hybrid systems" National Fuel cell Research Center University of California, Irvine.
16. G.P.Liu, J.G.Williams, B.Wang, D.Rees," Review and Analysis of fuel cell system Modelling and control".
17. L. Carrette1, K. A. Friedrich and U. Stimming," Fuel Cells Fundamentals and Applications".
18. A. Rezazadeh, M. Sedighizadeh, M. Karimi," Proton Exchange Membrane Fuel Cell control using a Predictive control based on Neural Network" International Journal of Computer and Electrical Engineering, Vol. 2, No. 1, February, 2010 1793-8163,".
19. M.O.Abdullah,"A Multipurpose mini hybrid fuel cell battery solar portable device for rural applications: Laboratory testing" International journal of Research and reviews in applied sciences, Volumes7,issue 4, 06.
20. B.Sreenivasulu,G.Vasu,V.Dharmarao,S.V.Naidu,"Performance study of A PEM Fuel Cell with 4 serpentine flow fields-Experimental study"International journal of Engineering science & Advanced Technology,Vol-2,Issue -2,291-296.
21. S.Rowshanzamir,M.H.Eikani,M.khoshnoodi,T.Eshgh Nimwar,"A Parametric study of the PEM fuel cell Cathode,"International journal of Engineering science,Vol.19,No.5-2,2008,Page 73-81.
22. Hui Li,Yanghua Tang ,Zhenwei Wang, **"**A review of water flooding issues in the proton exchange membrane fuel cell," Journal of power source"178(2008)103-117.
23. Lin wang, Attila Husar, "A Parametric study of Fuel cell Performances." journal of Hydrogen Energy28(2003) 1263-1272.
24. B.Sreenivasulu,S.V.Naidu,V.Dharmarao, G.Vasu, "A Theoretical simulation of a PEM fuel cell with 4-serpentine flow channel," International Journal of Computational Engineering,vol.2,Issue No.1,097-106.
25. www.horizonfuelcell.com.