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Harnessing Solar Power with Hydrogen Storage System

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ABSTRACT
This study presents hydrogen storage system to store solar energy in order to supply a highly reliable utility power. The system uses fuel cells to offer high power quality of low voltage as well as high current due to the electrochemical reaction and moreover it is also being investigated as an alternate power source for various applications like transportation and emergency power supplies. The paper explains the configuration and operation of fuel cell system with circuit model for a PEM fuel cell that can be used to design and analyze fuel-cell power system. Cost analysis of the storage system has been done which includes the major capital and operating expenses in storing hydrogen.
Keywords: fuel cell system, PEMFC, cost, barriers

I INTRODUCTION

Solar photovoltaic is a versatile electricity technology that can be used for any application from the very small to large. It is a modular technology that enables the electric generating systems to be built incrementally to match the growing demands. It gives domestic reserves of energy that can never deplete. Renewable are expected to play a significant role in delivering energy access to 1.6 billion people who lack access to modern energy services, because they may be more sustainable and less expensive than grid extensions. But in present solar systems there are many factors that are acting as barriers in wide spreading its development as:

- Intermittence nature of solar energy
- Inefficiency of the system (Less generated power, poor storage facility)
- Dependency on fossil fuels like petroleum etc for transportation is leading to the depletion of the fossil fuels
- Large initial cost
- Wastage of energy

To meet all these requirements, a new business–oriented approach needs to be developed in progress of implementation of solar energy to increase its feasibility in market. The solution to the problems defined above, can be solved by using an energy storage device in connection with solar power plant for following reasons [4] [5] [6].

- Energy storage could be valuable for balancing solar power generation with demand and for reducing generation uncertainty.
- Hydrogen as a storage medium for solar energy could provide “zero emission” clean fuel for transportation and help in preventing the depletion of fossil fuels.
- Appropriate use of storage during online operation of the plant can help in reducing the total costs, and therefore increasing the scope of trading solar power in the power markets.

Presently batteries are being used as an energy storage option, but as compared to fuel cells they have low down time (3.2 to 32 seconds per year against 9 hours for battery), low energy density with finite charging capacity. Moreover Fuel cells are now on the verge of being introduced commercially, revolutionizing the way we presently produce power. Its advent for the generation of electricity for portable, small and large-scale stationary and automotive purposes portends radical changes in electricity supply over coming decades. Fuel cells can use hydrogen as a fuel, offering the prospect of supplying the world with clean, sustainable electrical power. They offer the best criteria for meeting requirements of generation of power and zero emission vehicles (ZEV) and thus are expected to be the prime user of hydrogen in the near future. Also, the fuel cell power plants are twice as efficient as conventional power plants with high efficiency, excellent part load performance, low emission of regulated pollutants and wide size range. This paper discusses the new approach (solar hydrogen storage system) opted to envision the solar photovoltaic [4] [5] [6] [7].

II HYDROGEN STORAGE SYSTEM

In the system represented in Figure 1 electricity from photovoltaic panels is used to power an electrolyzer, a device which splits water (H_2O) into its elemental parts, hydrogen (H_2) and oxygen (O_2). The oxygen is then released into the air and the hydrogen is pumped into storage tanks, where it can be kept on site or transported to regions that need energy.

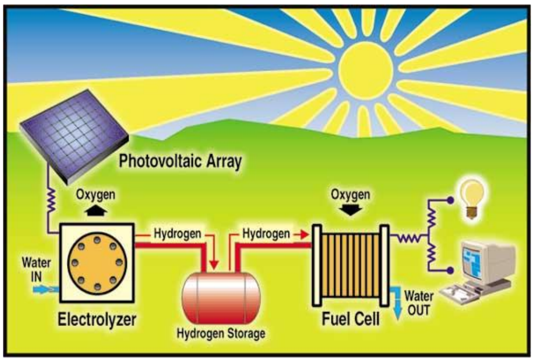

Fig 1: Hydrogen Storage System

At night or in bad weather, when solar energy is not available, the hydrogen is recombined with oxygen from the air in fuel cell, which directly converts the chemical energy in hydrogen into electricity. The only byproduct of this process is pure water. Then electricity produced from fuel cells is supplied to grid and to the local areas. Solar hydrogen allows us to use the power from the sun twenty-four hours a day, and provides us with an abundant, clean, efficient, locally produced source of energy.

In this system, fuel cells play the dominant role but they are a family of technologies which are generally categorized by the type of electrolyte. The most promising fuel cell types till today are Proton exchange membrane fuel cells (PEMFC), direct methanol fuel cell, Phosphoric acid fuel cells, molten carbonate fuel cells, Solid oxide fuel cells, Alkali fuel cell. These five types have similar structure and similar net chemical reactions but they are very different with respect to their operating characteristics, materials of construction, and potential application. In this system, PEMFC has been selected from all the specified types of fuel cell due its low working temperature, compactness, and easy and safe operational modes. Moreover the fuel cell systems based on PEMFC technology promise to provide a more efficient, cleaner technology for the automotive industry as the PEMFC meets the demands of rapid startup, acceleration, high power density.

III FUEL CELL SYSTEMS

A fuel cell system is composed of six basic subsystems: the fuel cell stack, the fuel processor, air management, water management, thermal management, and power conditioning subsystems. Its basic features are illustrated in Fig 2.

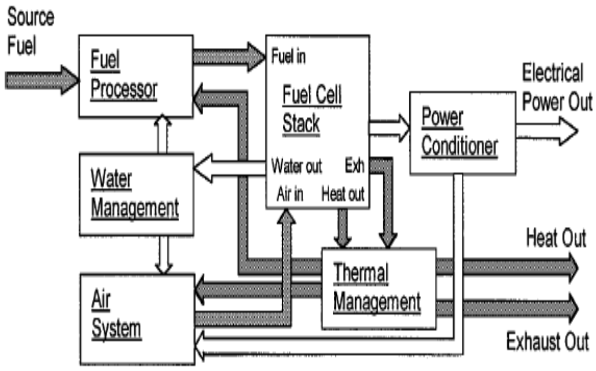

Fig 2: Schematic Diagram of Fuel Cell System

3.1 Fuel Cell Stack

It composes of number of fuel cells and in these all fuel cells are connected in series because a single fuel cell produces less than 1.6 V, so to increase the voltage that is required according to the system the fuel cells are interconnected [2] [3] [4] [5].

3.2 Fuel Processor

It is the device that converts the source fuel to a hydrogen rich fuel stream. Its complexity depends on the type of fuel cell system and the composition of the source fuel. For low temperature fuel cells the fuel processor is complex and also includes a desulfurizer, a steam reformer, shift converters, and a gas clean-up system to remove carbon monoxide from the anode gas stream. And for high temperature fuel cells, fuel processing simply consists of desulfurizing and preheating the fuel stream before introducing it into the internally reforming anode compartment of the fuel cell stack. More complex fuels may require additional steps of clean-up and reforming before they can be used even by the high temperature cells. For all types of fuels, the higher operating temperatures systems provide better thermal integration of the fuel cell with the fuel processor.

3.3 Air Management

Air Management is very important in fuel cell system because the fuel cell requires an oxidant, which is typically air. This air is provided to the fuel cell cathode at low pressure by a blower or at high pressure by an air compressor. The choice of whether to use low or high pressure air is a complicated one. When the pressure of the air is increased it improves the kinetics of the electrochemical reactions and leads to higher power density and higher stack efficiency and also it reduces the capacity of the air for holding water and consequently reduces the humidification requirements. But on the other hand, it reduces the net available power from the fuel cell system as more power is required to compress the air to a high pressure. Some of this energy can be recovered by expanding the cathode exhaust through a turbine before exhausting it to the atmosphere. Nevertheless, the air compressor typically uses more power than any other auxiliary device in the system. Furthermore, while the fuel cell stack performance actually improves at low power, the performance of the air compressor is usually poor at very low loads. Currently, most fuel cell stack designs call for operating pressures in the range of 1–8 atm. To achieve high power densities and to improve water management, most automotive fuel cell systems based on PEMFC technologies are operated at pressures of 2–3 atm.

3.2 Water Management

Water is required for a variety of purposes in the fuel cell system. In PEMFC systems, the reactant gases must be humidified in order to avoid drying out the fuel cell membrane. Water is available from the fuel cell reaction, but it must be removed from the exhaust gas, stored, and pumped to a pressure suitable for the various operations. In automotive applications, it is critical that the system operate in such a way that water condensed from the exhaust stream is sufficient for reforming and reactant humidification. Otherwise, the vehicle must periodically be recharged with water as well as fuel.

3.3 Thermal Management

A fuel cell stack releases thermal energy at a rate that is roughly equivalent to the electrical power that it produces. This thermal energy can be used for a variety of purposes within the fuel cell system, transferred externally to meet the thermal needs of a particular application, or rejected to the surroundings. Low temperature fuel cell systems are cooled by either air or a circulating liquid and for high temperature systems fuel cell stack operates at such a high temperature that all of the thermal energy from the cell reaction can be transferred to the reactant gases without heating the exhaust beyond the operating temperature limit of the stack. With these systems, thermal energy is available at a high enough temperature to drive the reforming reaction either internal or external to the stack. Thermal energy from the stack exhaust can also be used to preheat the incoming air stream. Proper integration of the fuel cell system is essential to insure that thermal energy available from the stack is used for the most appropriate application [14].

3.4 Power Management

It is the final component of the fuel cell system and it converts the electricity available from the fuel cell to a current and voltage that is suitable for a particular application and supplies power to the other auxiliary systems. Fuel cell stacks produce direct current at a voltage that varies with load. A switching power converter is used to match the voltage produced by the fuel cell to the needs of the application and to protect the fuel cell from over current or under voltage conditions. If the application requires alternating current, the electricity is processed through an inverter, which constructs single or three-phase waveforms as required by the application. If the application involves interconnection with the utility grid, then the power management system must also be able to synchronize the frequency of the fuel cell system power with the utility power and provide safety features to prevent the fuel cell system from feeding power back into the utility grid if the grid is off-line.

IV OPERATION OF FUEL CELL SYSTEMS

The operation of a fuel cell system is mainly determined by the manager and energy demand. An energy user can run the fuel cell system or buy energy from a service provider, who runs the plant. A service provider can group some customer and smooth fluctuate energy demand. If a utility operates fuel cell systems, it can sell energy to the customer and produce system services, like reactive power, and is able to optimize load flow. A fuel cell system has two main operating modes as [1] [4] [12] [14].

4.1 Irregular Power Injection

Distributed generators feed base load, if they are not controlled by local distribution company or power injection is not correlated to load of user. An irregular power injection makes load forecast more difficult for local distribution company, because change of load is superimposed by fluctuating power injections. As a result local distribution company has to provide more controlling power range. Heavy power flow occurs, if power injection is not correlated to load of the user and hence losses increase.

4.2 Power Production According to Typical Load Characteristic

The load characteristic of a distribution network can be divided into several typical load characteristics. The typical load characteristic of residential buildings can be scaled to a single house by means of known electric work per year. A fuel cell supplying a residential building can follow the typical load characteristic in a vast range. Feeding according to a typical load characteristic do not supply peak load, but on low load demand energy is fed into network. The power system can also be used as energy storage.

In this the excessive power is fed into system and peak load is provided by the power system. The feeding of power according to load characteristic offers advantages to the local distribution company. The local distribution company incorporates power injection in load forecast, balance and accounting. With this easy net metering is possible and annual residual electric work can also be charged or paid. Moreover it also enables all customers with fuel cells access to the network. Voltage-rise because of distributed generation is also reduced by load. Infeed from medium-voltage network to urban network is diminished and hence distribution transformer and medium-voltage network are relieved.

4.3 The "Virtual Utility" With Fuel Cells

The disadvantage of running a fuel cell along a typical load characteristic is that load demand may differ from that typical load characteristic. The local distribution company takes the risk if peak load and maximum power in feed of distributed generators are not at the same time. This allows the local distribution company to control many distributed generators as a large power station ("virtual utility"). Hence fuel cell systems can supply peak load and reactive power to distribution network if required. This control scheme has to take users heat demand into account because cogeneration of heat and power only exists if produced heat is utilized. As a consequence heat storage is required. Remote control is only feasible if the local distribution company owns the fuel cell system in order to have unrestricted access. The local distribution company can optimize load flow in low-voltage network and control system voltage. Disadvantages of network control with fuel cells as a "virtual utility" are more expenditure of measurement, data transfer, data processing and network management.

V POWER SYSTEM INTERCONNECTION OF FUEL CELLS

5.1 Power Conversion of Fuel Cells

In this cell the voltage level is adjusted according to the required voltage and then the power is converted from dc to ac. As the single cell of a fuel cell has a non-linear current-voltage characteristic with a non-load voltage of 1.2 V. The cells are stacked to get an appropriate voltage level. [2] [3] [4] [5] [11].

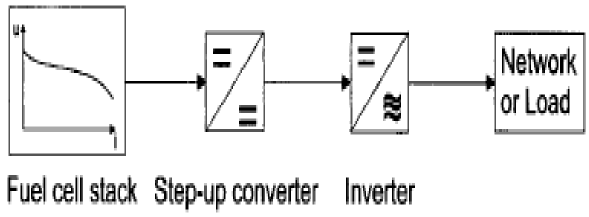

Fig 3: General Power Conversion of Fuel Cells

A step-up converter adjusts the voltage level of the fuel cell stack in order to feed an inverter as shown in Fig 3. The inverter itself feeds a three phase or one-phase alternating current into power system or load. Infeed of single-phase alternating current into power system is limited to a generating capacity of 4.6 kVA.

5.2 Voltage Variation

Voltage variation always takes place in a system as additional power injection to power system leads to a voltage rise. And voltage rise compared to voltage without dispersed generation depends on short circuit power at point of common coupling and power injection. Voltage rise of a single unit can be calculated with equation as following:

$$\Delta u = S_{FC} . e^{j(\psi_{sc,pcc} + \psi_{FC})}$$

Where, Δ u = voltage rise, S_{FC} = complex power of fuel cell, Ψsc, pcc = short-circuit angle at point of common coupling, Ψ_{FC} = power-factor angle of fuel cell, and $S_{sc,pcc}$ = short-circuit power at point of common coupling

Voltage variation due to functional switching at low voltage network is limited to 3% of nominal voltage according to the present standards. And if a fuel cell system feeds only active power, voltage rise can be computed with the following equation, which is also shown in the figure 4.

$$\Delta u = \left[1 + 2 . \frac{P_{FC}}{S_{sc,pcc}} . \text{Cos}(\Psi sc, pcc) + \frac{P^2_{FC}}{S^2_{sc,pcc}} - 1 \right]^{1/2}$$

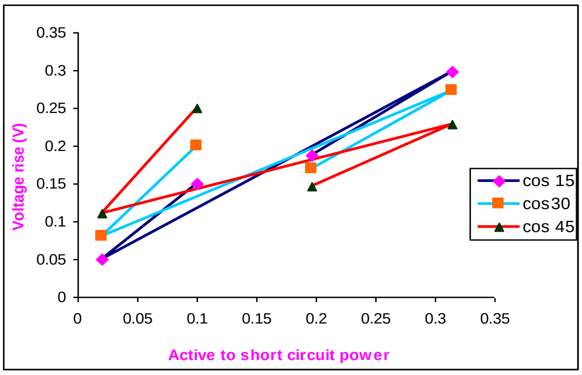

Fig 4: Effect of Voltage Rise on Active to Short Circuit Power

It concludes that with a short-circuit power of 1.0 MVA and a short-circuit angle of 45" at point of common coupling an active power infeed of 50 kW leads to a voltage rise of 3.6%. Hence-power injection is to distribute to several independent smaller units.

5.3 Short-Circuit Performance

5.3.1 Short-Circuit Performance of A Single Fuel Cell System

Fuel cell systems are connected via a tie circuit-breaker to power system. The protection scheme of a fuel cell system consists of an under voltage and over voltage relay. In case of short-circuit fault the inverter contributes short-circuit currents until under voltage protection relay trips tie circuit-breaker. Pick-up values are 1.1 p.u. of nominal voltage for over voltage relay and 0.8 p.u. of nominal voltage for under voltage. Current injection of inverter during short-circuit fault on network depends on control of inverter. Since inner control loop of a self-commutated inverter controls current, the fuel cell inverter acts as a current source and feeds operating current to network.

5.3.2 Short-circuit faults on higher-level networks

Short-circuit faults on high-voltage and medium-voltage networks lead to a voltage dip on low-voltage network until faulted branch is disconnected or fault is cleared and network is restored. If a fault causes a disconnection of medium-voltage feeder, voltages on connected low-voltage networks fall down to zero. Fuel cell systems must shutdown in order to avoid feeding to short-circuit and to ensure safety for repair service. After restoration of network and voltage recovery, fuel cell systems may synchronize automatically to system voltage and connect to network. Voltage dip on low-voltage networks connected to a faultless medium-voltage feeder occurs only a few hundred's milliseconds until faulted feeder is disconnected [11].

Voltage level depends on network topology and distance of fault to feeding high/medium-voltage transformer. Since fuel cell systems at low-voltage network feed only their rated current, their impact on short-circuits current on medium-voltage network is negligible. It is not necessary to disconnect and shutdown fuel cells on faultless feeders. If the distribution transformer is equipped with a reverse-current relay, the pick-up value should set to rated current to avoid spurious tripping due to feeding of distributed generation to medium-voltage network. The same annotations are valid for faults on high-voltage network with fuel cells on low-voltage networks. If the high-voltage network is meshed, then short-circuit on the high voltage network results in a voltage dip on low-voltage networks for some hundred's milliseconds. Hence instantaneous disconnection of fuel cell systems on low-voltage network is not necessary.

VI GRID CONNECTION OF FUEL CELLS

Fuel cells are connected to grid through Power conditioning unit (PCU) which converts the produced DC power into AC power and adjusts the voltage and frequency levels to suit the local grid conditions. By applying the Pulse width Modulation (PWM) technique to the converter, it allows the Fuel Cell to represent with a voltage at fundamental frequency using the following equation for the injected voltage magnitude:

$$V_{ac} = m.\ V_{FC}.\delta$$
$$I_{FC} = m.\ I_{ac}.\ \cos(\varphi)$$
$$V_{FC} = E_0 - R_{FC}\, I_{FC}$$

Where, m is the amplitude modulation index of the converter and δ is the firing angle of the converter with respect to the phase angle of the bus voltage. The voltage magnitude V and the firing angle (φ) are controllable in the range of

$$Vmin < V < Vmax$$

And $0 < \delta < 360$

6.1 Control Loops of PCU

- **Power control:** It is done by adjusting the firing angle of the inverter for fast transient variations and fuel flow input control for slow variations.
- **Voltage control:** It is done by adjusting the modulation index of the converter, which

affects the magnitude of the converter output voltage.

Also by using the fast response of the power conditioning unit, the maximum power can be used to alleviate transients when fault occurs.

6.2 Limitations of PCU

- **Overused fuel**: u > 90% (fuel starvation and permanent damages to cells)
- **Underused fuel**: u<70%, (The cell voltage would rise rapidly).
- **Under voltage:** stack voltage < certain point, (Loss of synchronism with the network).

VII COST ANALYSIS FOR STORAGE SYSTEM

Hydrogen storage is a key enabling technology for advancement of hydrogen and fuel cell power technologies but this is also a main technological problem of a viable hydrogen economy. The primary difficulty with using hydrogen for grid energy storage is that converting power to hydrogen and back is not cheap. An analysis is performed to estimate the storage costs based on the major operating and capital expenses.

7.1 Compressed Gas Storage Methodology

For compressed gas, the storage requirements are calculated from the production rate (assumed 450kg/hr) and storage time. In tables 1 and 2 some assumptions are made for both capital and operating cost as:

Table 1: Capital Cost Assumptions

Components	Base size	Base cost	Base pressure	Size exponent	Pressure factor
Compressor	4000 kW	$1000 /kW	20MPa	0.80	0.18
Compressed gas vessel	227 kg	$1323 /kg	20MPa	0.75	0.44

Table 2: Operating Cost Assumptions

Components	SI units
Compressor power (.1 to 20 MPa)	2.2kWh/kg
Compressor cooling (.1 to 20 MPa)	50L/kg
Electricity cost	$.05/kWh
Cooling water cost	$0.02/100 L
Operating Days	350/yr
Depreciation	22 yr

- **Annual production** = flow * Operating days
- **Energy (kW)** = Flow * Compressor Power *[ln (P / .1 * 10^6Pa)] / [ln (20* 10^6Pa / .1 * 10^6Pa)]
- **Cooling water** = flow * compressor cool *[ln (P / 0.1 * 10^6Pa)] / [ln (20* 10^6Pa / 0.1 * 10^6Pa)]
- **Compressor capital cost** = (Comp cost * Comp Size) * (energy / comp size) $^{\text{comp exp}}$ * (P / comp press) $^{\text{CP Exp}}$
- **Tank capital cost** = (Tank Cost*Tank Size) * [storage * (Tank press/ P)] $^{\text{Tank exp}}$ * (P/Tank press) $^{\text{TP Exp}}$
- **Total capital cost** = Tank Capital cost + Comp capital cost
- **Depreciation cost** = Total capital cost / life
- **Energy cost** = energy * electricity cost
- **Annual energy cost** = Energy cost * operating days
- **Cooling cost** = cooling * cool water cost
- **Annual cooling cost** = cooling cost * operating days
- **Total annual cost** = Depreciation cost + Annual energy cosz+ Annual cooling cost
- **Energy (life)** = energy cost / flow
- **Depreciation (life)** = Depreciation cost / production
- **Cooling (life)** = cooling cost / flow = .05
- **Total cost (life)** = Depreciation (life) + Energy (life) + Cooling (life)
- **Compressor capital cost (life)** = Compressor capital cost / (production * life
- **Total capital cost (life)** = Tank capital cost (life) + Compressor capital cost (life)
- **Tank capital cost (life)** = Tank capital cost / (production * life)
- **Total cost (life)** = Total operating cost (life) +Total capital cost (life)

On the basis of above and through programming in C it has been concluded that the total storage cost for this methodology is $1678945.192, where this storage cost includes both capital ($ 1586147.575) and operating ($ 92797.617) cost. This high cost is mainly involved due to the energy required to compress the hydrogen. Further this storage cost depends upon various factors as storage time, pressure, hydrogen flow etc. which have been represented in Fig 5, Fig 6 and Fig 7.

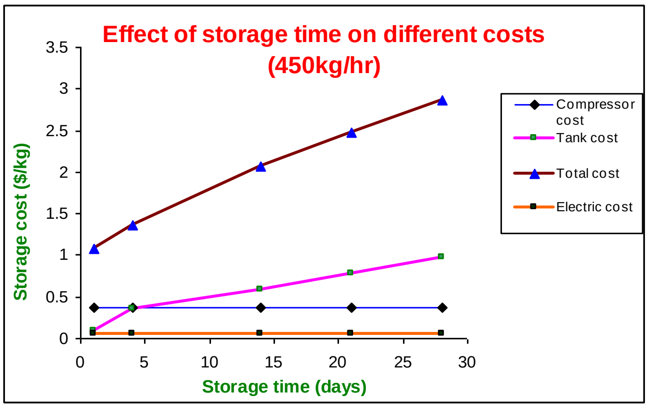

Fig 5: Effect of Storage Time on Different Cost

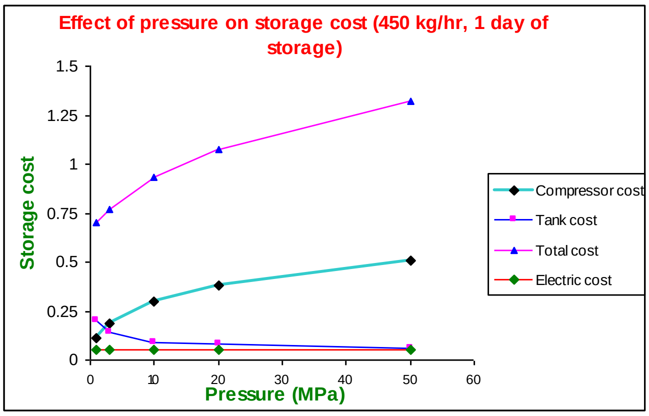

Fig 6: Effect of Pressure on Different Cost

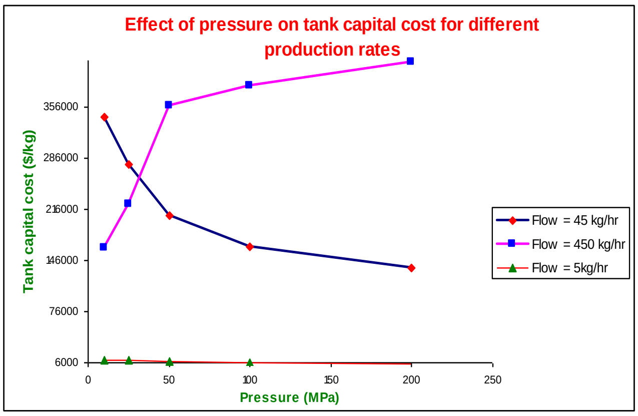

Fig 7: Effect of Pressure on Tank Cost

These all results conclude that by changing any of the above factors there is a change in cost and moreover, at the end of 22 years the whole money that has been invested in the system is returnable with profits and the total cost is only $1.074 that has to be paid. By applying above mentioned algorithm, the cost can be calculated for hydrogen storage system of any capacity [14].

XIII LIMITATIONS

The fuel cell is the versatile technology and the 21st century will be the century of fuel cell. But, in spite of all this fuel cell has some limitations (supply of platinum, carbon monoxide poisoning) that are acting as barriers in wide spreading its development [1].

8.1 Carbon Monoxide (CO) Poisoning

The major contaminant of the PEMFC system is carbon monoxide. The platinum-alloy catalyst used in proton-exchange membrane (PEM) fuel cell anodes is highly susceptible to carbon monoxide (CO) poisoning. CO reduces the catalyst activity by blocking active catalyst sites normally available for hydrogen chemisorptions and dissociation. The reaction kinetics at the anode catalyst surface can be used to estimate the decrease in cell voltage due to various levels of CO contamination in the inlet fuel stream.

When the hydrogen fuel is obtained from renewable source then in fuel cell no CO poisoning takes place but when the hydrogen fuel is obtained from reformed fuel, such as Steam-reformed methanol then the CO contamination takes place. When the uncontaminated hydrogen anode gas enters the fuel cell stack, it electro oxidizes on the anode platinum catalyst in two steps. The first step is the rate-limiting step when hydrogen dissociates requiring two free adjacent platinum sites. The second step involves the production of hydrogen into two free platinum sites, two hydrogen ions and two electrons:

$$H_2 + 2(Pt) \leftrightarrow 2(Pt - H)$$
$$2(Pt - H) \leftrightarrow 2(Pt) + 2H^+ + 2e^-$$

For **CO contaminated** hydrogen gas stream:

$$CO + Pt \rightarrow (Pt = CO)$$
$$2CO + 2(Pt - H) \rightarrow 2(Pt = CO) + H_2$$

In above equation CO can adsorb onto either a bare platinum site or a platinum-hydrogen site. These adsorbed CO blocks active platinum sites at the anode, as shown in the representation in Figure 8, which further leads to the inhibition of reactions for uncontaminated gas stream and causes performance losses. Over time, these losses can decrease performance significantly with increasing adsorption of CO. This appears to be a slow process, requiring considerable time to reach steady-state conditions with CO in the inlet anode fuel stream.

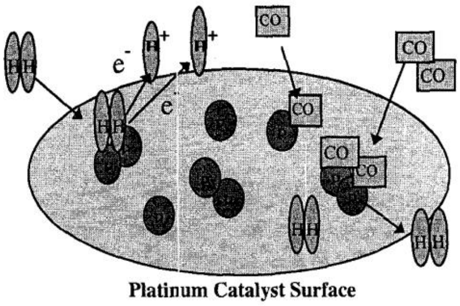

Fig 8: Schematic of the CO Adsorption on the Platinum Catalyst

It has been noted that steady-state current-voltage curves with CO contamination only occurred after about 120-210 minutes and that all open circuit voltages were not affected by the presence of CO. To avoid this contamination PtRu alloy catalyst is used for improving the CO tolerance of the anode in PEM fuel cells. The ratio between Pt and Ru can be varied according to requirement. The fuel cell cathode is pure Pt and the anode catalysts are pure Pt, $Pt_{.7}Ru_{.3}$ and $Pt_{.5}$ $Ru_{.5}$. The electrode catalyst loadings for both the anode and cathode are 1 mg/cm^2. When the anode gas is feeded it is normally humidified and the presence of water vapor appears to be a key to the improvement of CO-tolerance. Water adsorbs on the anode catalyst as: [1]

$$Pt + H_2O \rightarrow Pt\text{-}OH + H+ + e^-$$
$$Ru + H_2O \rightarrow Ru\text{-}OH + H+ + e^-$$

And then it undergoes as

$$Pt - CO + Ru - OH \rightarrow Pt + Ru + CO_2 + H^+ + e^-$$

In the Pt and $Pt_{.5}$ $Ru_{.5}$ anode catalysts the CO poisoning effects are reversible. There are no performance differences between them. Only difference is that the number of surface Pt atoms in the $Pt_{.5}Ru_{.5}$ anode catalysts is about 50% lower than the pure Pt catalyst indicating that hydrogen oxidation is not affected by the presence of Ru at these loadings. Secondly the voltage drop is considerably less with the Pt-Ru catalyst when exposed to CO.

8.2 Platinum Supply

At the lowest level of consumption by the American public, the current prices for any type of alternative fuels vehicle can range higher in cost compared to an equivalent internal combustion automobile. Even though in the long run the vehicle would more than make up the cost in fuel mileage the initial sticker shock will drive many consumers away. Some of the largest costs will be driven down with mass production but the cost of certain materials will remain a sore point. The most controversial component of the PEMFC, and ironically the most important, is the platinum catalysts. Platinum has long been held as the best material to induce the oxidation of a reactant, it is also considered to be a ‘precious metal’ resulting in high costs and lower availability. Another unfortunate result of this material is that the U.S. does not mine enough platinum to satisfy the current domestic demand. Currently 68% comes from South Africa and 24% from Russia [4]. Neither country has had a stable economy for the past decade. It has been asked whether we would be substituting one foreign dependence (oil) for another. The answer is a meek yes and no. Yes we will be dependent on foreign countries for a critical material but the platinum has a onetime use and does not need to be replenished once the fuel cell has been assembled whereas gasoline has to constantly be replenished in order to continue operating. So yes, we will be replacing one foreign dependence for another but the amount of dependence is clearly lopsided in the comparison.

IX CONCLUSION

It has been shown, for the solar photovoltaic industry to make a significant entrance into the market, new business–oriented approach needs to be developed in progress of implementation of solar energy to increase its feasibility in market. This progress can be made by applying fuel cell technology and by focusing on the overcoming current barriers.

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