Use of Renewable Energy Resources

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Absract: **The electricity requirements of the world including India are increasing day to day and the power demand has been running ahead of supply. It is also now widely recognized that the fossil fuels (i.e., coal, petroleum and natural gas) and other conventional resources, presently being used for generation of electrical energy, may not be either sufficient or suitable to keep pace with ever increasing demand of the electrical energy of the world. Also generation of electrical power by cold based steam power plant or nuclear power plants causes pollution, which is likely to be more acute in future due to large generating capacity on one side and greater awareness of the people in this respect. The recent severe energy crisis has forced the world to develop new and alternative methods of power generation, which could not be adopted so far due to various reasons. The magneto-hydro-dynamic (MHD) power generation is one of the examples of a new unique method of power generation. The other non-conventional methods of power generation may be such as solar cells, fuel cells, thermo-electric generator, thermionic converter, solar power generation, wind power generation, geo-thermal energy generation, tidal power generation etc.**

This paper elucidates about Different Energy sources, why we are going for non-conventional energy sources, Different non-conventional energy sources & comparison between them, about fuel cells and their applications.

I. INTRODUCTION

Why we are going for non-conventional energy sources?

ENERGY SOURCES

- CONVENTIONAL
- NON-CONVENTIONAL

Basically the energy sources are two types; they are conventional energy sources like coal, petroleum, natural gas etc. & non-conventional energy sources like solar cells, fuel cells, thermo-electric generator, thermionic converter, solar power generation, wind power generation, geo-thermal energy generation, tidal power generation etc.

Fast depletion of conventional energy sources made us to look after alternate energy sources such as magneto-hydro-dynamic (MHD) power generation and other non-conventional methods of power generation.

Different Non-conventional methods of power generation & their efficiencies:

S.NO	METHOD	EFFICIENCY	
		FUTURE	PRESENT
1.	MHD Power generation	Around 50%	Up to 60%
2.	Thermo-electricpower generation	Around 3%	Up to 13%
3.	Thermionic converters	Around 15%	Up to 40%
4.	Photo-Voltaic or solar cells	Around 15%	—
5.	Fuel cell technologies	Around 50%	Up to 60%
6.	Solar power generation	Around 30%	Up to 50%
7.	Wind power generation	Around 30%	—
8.	Geo-thermal power generation	Around 15%	—

Fig-1

From the above table fuel cell technologies having higher efficiency compared with other methods of electric power generation. Another reason for the interest in fuel cells is; cost per kW of power is independent of size (or rating) of the fuel cells. The other merits are as follows.

II.MERITS OF FUEL CELLS

1. The unit is lighter and smaller and requires little maintenance because of absence of mechanical parts
2. They cause little pollution and little noise.
3. No overhead line is required.
4. Fuel can be used more effectively than in a central power plant.
5. They can become remarkable home units.
6. High efficiency of about 50% compared to 30% of conventional power systems.
7. Fast startup and fast load response.
8. A fuel cell gives a few times more electrical energy per unit weight as compared to a turbo generator or a storage battery.
9. A variety of fuels such as methane, ethane, ethylene, acetylene, propane, butane, benzene, methanol, ammonia, hydrazine, LPG, biogas or coal gas can be used.

Hence in this paper we want to deal the fuel cell technologies mainly because of its inherent advantages explained above.

III.FUEL CELLS INTRODUCTION TO FUEL CELLS

The basic concept involved in any modern fuel cell for electric power generation is the electrochemical reaction between hydrogen and oxygen in the presence of catalysts, which produces electrical energy in the form of a DC current. The by-products are heat and water. Since hydrogen has one of the highest chemical reactivity's, it is commonly used as either pure hydrogen or hydrogen rich fuel in most modern fuel cells. The fuel is supplied on the anode side. The anode reaction in fuel cells is either direct oxidation of hydrogen or methanol or indirect oxidation via a reforming process for hydrocarbon fuels. The cathode reaction is oxygen reduction from air in most fuel cells. Since the electricity in a fuel cell is not produced through the use of thermal energy, fuel cell efficiency is not limited by the Carnot efficiency.

The basic components of a fuel cell are the electrodes (anode and cathode), the electrolyte and the catalyst. The anode consists of a porous gas diffusion layer as an electrode and an anodic catalyst layer. It conducts electrons generated at the catalyst/anode/electrolyte interface to the external electrical circuit, which eventually returns to the cathode An electrolyte is formed by an ionic bond, conducts protons or ions to the opposite electrode internally, thus completing the electric circuit.

The electrolyte is considered the heart of the fuel cell. It consists of a solid membrane having a proton-conducting medium (e.g., moistened with water for PEMFC or DMFC), and a solid matrix with a liquid ion-conducting electrolyte (e.g., PAFC, MCFC), or a solid matrix having ion-conducting characteristics (e.g., SOFC). The cathode consists of a porous gas diffusion layer as an electrode and a cathodic catalyst layer. It conducts electrons returning from the external electric circuit to the cathodic catalyst layer. Catalysts speed up the reaction without actually participating in the reaction. The highest oxidation rates and hence current densities are found at sites having significant catalyst activity.

IV.BRIEF THEORY AND OPERATION

For the hydrogen/oxygen (air) fuel cell, the overall reaction is: $H_2 + \frac{1}{2} O_2 = H_2O$. The product of this reaction is water released at the cathode or anode depending on the type of fuel cell. For PEM fuel cell, hydrogen is oxidized at the anode as given by the reaction, $H_2 = 2 H^+ + 2 e^-$. Electrons generated at the anode are flown through external load to the cathode. Protons (H^+) are migrated through the proton exchange membrane to the cathode. The protons and electrons reached at the cathode react with oxygen from air as given by the reaction, $2 H^+ + 2 e^- + \frac{1}{2} O_2 = H_2O$.

The reversible open circuit voltage E_0 for hydrogen/oxygen fuel cells at standard conditions of 25°C and 1 atm pressure is 1.23 V. This voltage level is too low to be useful. Most of electronic products require a power source with much higher voltage. Many cells are connected in series called a cell stack to produce useful voltages (which is the sum of individual cell voltages).

The cell current depends on the area (the size) of a cell. In general, the larger the cell area, higher will be current generated. Hence, the cell current is usually presented in terms of the current density, mA/cm2 or A/cm2. Cells are connected by the bipolar plates or interconnect.

They serve as the current pathway from cell to cell in a stack. Besides collecting current, bipolar plates also have gas flow channels on each side through which the gases [fuel (hydrogen) and oxidant (air)] evenly distribute through the entire cell. Bipolar plates may have cooling channels depending on the stack-cooling requirement.

The reversible open circuit voltage E for given operating conditions depends on the operating temperature T, partial pressures (P with appropriate subscripts) of the reactants and products in the fuel cell, and the number of electrons generated for each molecule of the fuel, and are given by the Nernst equation. Actual voltages generated in a fuel cell are always less than the Nernstian voltage due to various losses associated with a fuel cell and the fuel cell system.

These voltage losses for a fuel cell are due to activation over potential, ohmic over potential and concentration over potential. Activation over potential is the voltage loss to overcome the electrochemical barrier of the electrochemical reaction occurring in the fuel cell. Ohmic over potential loss is the voltage loss due to internal electrical resistance of the cell. Concentration over potential is the voltage loss attributes to the depletion of reacting species on the electrode.

V.TYPES OF FUEL CELLS

The different types of fuel cells are as follows.

- Alkaline Fuel Cells (AFC).
- Proton Exchange Membrane Fuel Cells (PEMFC).
- Direct Methanol Fuel Cells (DMFC).
- Phosphoric Acid Fuel Cells (PAFC).
- Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cells (SOFC).

Among all these types the general type of fuel cell technology used is Proton Exchange Membrane Fuel Cells (PEMFC). So the following sections we will see the basic PEMFC, working and its applications etc.

PROTON EXCHANGE MEMBRANE FUEL CELL (PEMFC)

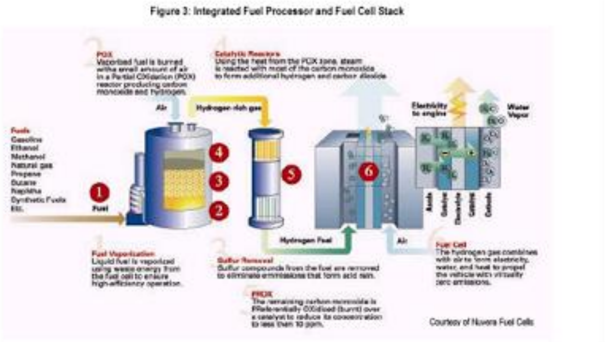

Fig 2: overview of a fuel system

The important application of the PEMFC is for automotive power because of low operating temperatures and hence can handle fast startups and transients as experienced in automotive applications. The PEMFC is also being considered for portable power, small-scale stationary power and UPS (uninterruptible power supplies). While the PEMFC was first used in the first Gemini Space flight to supply electric power and water to astronauts, the membrane was unstable and the PEMFC was discarded in favor of the Alkaline Fuel Cell in the succeeding space flights until Nafion was discovered in 1970s. The utilization of Nafion membrane has now extended PEMFC operating time up to 3,000 hrs. Through R&D efforts of the last two decades, the precious metal loading of PEMFC has been reduced tenfold, from mg/cm2 to tenth of mg/cm2. The PEMFC power density (3.8-6.5 kW/m2) is one of the highest among all modern fuel cells being considered for electric power generation. PEFC commercialization in the forefront among all types of fuel cell. Extensive R&D efforts are going on several fronts to make the PEMFC power plant much reliable and durable system as well as cost competitive and very compact for automotive applications. There are several important research areas where a significant impact can be made on the improved performance, reliability, and cost effectiveness.

THE CELL:

The proton exchange membrane fuel cell (PEMFC) is a low temperature fuel cell operating at around 80°C. It has a polymer (plastic) membrane (Nafion/Dow) which when hydrated with water becomes the electrolyte for the proton transfer from the anode to cathode. The gas diffusion layer of anode and cathode are porous thin carbon papers (graphite sheets) or cloth. Thin layer (about 10-100 µm) of Pt or Pt/Ru catalyst layer is deposited on each side of the membrane.

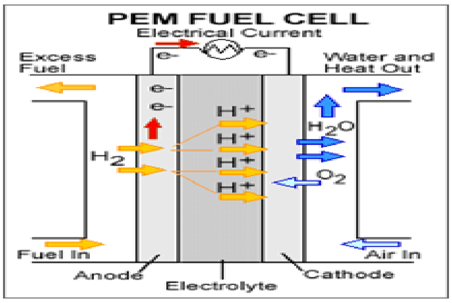

Fig-3 PEM fuel Cell

The theoretical voltage for a PEMFC is 1.23 V, while the realized voltage is 0.5-0.9 V. The activation over potential of oxygen reduction reaction (ORR) at the cathode is about four times larger than that of hydrogen oxidation reaction at the anode. Hence, if the cathode activation over potential can be reduced, a significant gain in the PEMFC performance can be realized. Currently, the platinum and platinum/ruthenium are used in the PEMFC and they play a critical role on the current achievable performance levels. The use of the Pt & Pt/Ru catalysts has been considerably reduced in the last 30 years from 28 to 0.2 mg/cm2 of the cell area. This amount must be further reduced if the PEMFC is going to be used for automotive power generation, where the cost of Pt used can go up due its use in a large number of vehicles produced yearly. Also, no significant reduction in activation over potential has been achieved in the last 20 years or so. This is one of the most important areas of research needed to significantly increase the performance and efficiency of the PEMFC at the cell level.

Although the modern technology enables reducing the particle size of the catalyst down to 2-5 nm, the fundamental reaction mechanisms of ORR on nano-scale platinum or platinum/ruthenium catalysts are still not clearly understood. Many bimetallic catalysts, such as Pt-Ni and Pt-Co, and trimetallic catalyst are being investigated. There is a need of computational nanoscience analysis to achieve optimum use of the catalyst with proper catalyst structure and composition.

Particularly, oxygen reduction reaction at the cathode needs to be defined where the major activation over potential occurs.

Since the carbon monoxide poisons the Pt catalyst, currently the CO amount in the incoming hydrogen is controlled in the fuel reforming process to less than about 10 ppm. Again novel ways of higher CO tolerant catalysts need to be investigated which will potentially reduce the cost of fuel reforming process by reducing the size of the preferential oxidation reactor or removing it.

The performance of a PEMFC depends on the proton conductivity of the currently used Nafion membrane. This membrane must be well hydrated for good proton conductivity and must also be operated at temperatures lower than 100°C for the durability of the membrane. Increasing the operating temperature of the fuel cell will result in faster electrode kinetics and will significantly improve the cell performance (higher is the operating temperature, the lower will be activation over potential). A new membrane material with better thermal stability is needed for automotive application. An ideal membrane requires less or no humidification and can operate at higher temperatures without affecting the proton conductivity and degradation; the material should be chemically and mechanically stable and provide adequate barrier to fuel crossover and internal current leakage. Thinner membranes are desired to reduce the ohmic losses, but at the same time should be able to withstand high-pressure differentials. Reduction in the membrane cost is highly desirable since it represents about 18% of the cost of the fuel cell. Of course, as the production volume increases, the cost of membrane will go down while the cost of platinum will increase due to more demand of platinum.

Water management in the PEMFC is an extremely important and complex problem. Water is generated in the cathode due to the oxygen reduction reaction. Water in the membrane is migrated from anode to cathode due to electro-osmotic drag. The membrane on the anode side may lose water while the membrane on the cathode side may experience excessive water. It is a diligent balance of controlling the humidification on the anode and water evaporation on the cathode. There must be sufficient water in the polymer electrolyte to maintain ion conductivity of membrane and to stop the crossover of hydrogen fuel. Dehydration of the membrane causes substantial increase of ohmic over potential in the membrane that results in a major loss in the cell efficiency.

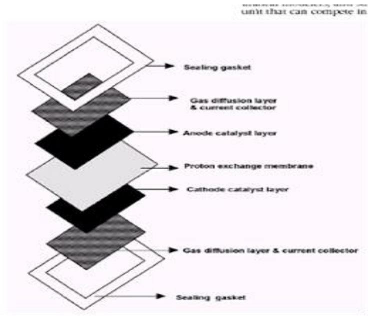

Fig-4

The cathode should be properly moistened to diffuse sufficient water in the membrane for required ionic conductivity. Yet, it should not be flooded. Excessive water in the cathode blocks the pores, which are the diffusion pathways for oxygen. Having proper hydrophilic/hydrophobic properties of the gas diffusion layer on the electrodes and proper humidity of the inlet gas streams does water balance in the membrane. The water must be evenly distributed in the membrane throughout the cell. In practice, the air flowing over the cathode may be dry at the entrance; just right in the middle, and fully saturated near the exit so that it cannot dry off any more excess water. Water management issue becomes more severe for increasing size and number of cells in the stack. High water pressure in reactant flows reduces the cell voltage and increases over potential at the cathode. Water condensation, electrode flooding and occlusion of gas channels could lead to operational failure.

The thermal management issue is coupled with the water management. Heat generated in the stack is approximately the same order of magnitude as the electricity generated .The stack coolant mainly removes this heat since there is negligible amount of heat carried away by the exhaust gases whose temperature is at the operating temperature of the stack. If the cell temperature is too low, the output power is low and water condensation problem may lead to cell operational failure. If the cell temperature is high, it leads to local or global cell dehydration of the membrane. This may lead to the loss of performance due to increased internal resistant and possible explosion due to the crossover of fuel.

Better MEA (membrane electrode assembly) structure and flow channel design are needed to improve water and thermal management at the cell level. Quantification of temperature distribution in a membrane/electrode over its entire surface area is important to understand the current distribution and optimization of the cell performance.

The Stack:

The flow distribution and associated pressure drop of hydrogen and air in the cell stack is a real issue for high voltage and high power density performance. Novel designs of the gas flow fields (channel designs) on the anode and cathode sides are needed to make cost effective high performance gas flow field plate designs that also reduces parasitic losses of flowing the fuel and oxidant.

Stack cooling in a fuel cell generating over 10 kW power is a challenging problem. Flowing a coolant through the passages made in a bipolar plate does the stack cooling. Design of cooling channels for stack cooling needs to be optimized from the viewpoints of cooling, parasitic pressure drop and cost considerations. Also, the coolant should be non-conductor or dielectric to prevent voltage loss or short-circuiting. Water as a coolant can pose a serious problem in cold climates for automotive applications. A low cost dielectric fluid that can operate at very low temperatures (up to -40°C) is needed for cooling the fuel cell stack. Currently, the water-glycol mixture is being considered as coolant for automotive applications with onboard ion exchange resin filler containing both anion and cat ion exchange resins to remove free ions.

Graphite is used as the bipolar plate in the laboratory and prototype fuel cells. Flow channels and fuel/air/coolant distribution manifolds of the bipolar plate are individually machined. Bipolar plate represents about 80% mass of the fuel cell, almost all volume and about 14-24% of the cost of the fuel cell†. Two processes under developments are injection molding and metal stamping/forming. These processes have been industrialized for low cost, mass production of electronic and automotive parts. Composite material, such as carbon powder and resin, is used for molding of bipolar plates. Stainless steel is used as the bipolar plate for special applications. Hence, the current direction is to go from graphite to metal bipolar plates or composite material to reduce the volume and the cost.

Further research is needed to extend the lifetime and stability of the bipolar plates made from these processes. This is because the fuel cell operating environment is very acidic and corrosive. The hydrogen leakage in the composite material or embitterment of the metal is also the problems with bipolar plates.

Fluorine and sulfur leaching problem associated with Nafion based membranes should be addressed because the resultant low pH level water coming out from fuel cells may corrode/ruin the road surface when the PEMFC is used in the automotive applications needed to extend the lifetime and stability of the bipolar plates made from these processes. This is because the fuel cell operating environment is very acidic and corrosive. The hydrogen leakage in the composite material or embitterment of the metal is also the problems with bipolar plates.

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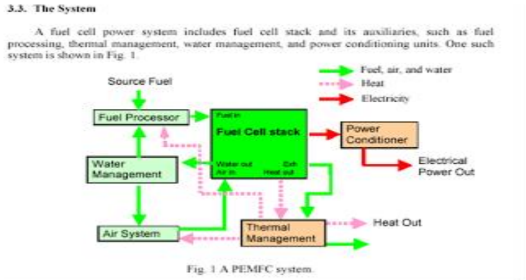

3.3. The System

A fuel cell power system includes fuel cell stack and its auxiliaries, such as fuel processing, thermal management, water management, and power conditioning units. One such system is shown in Fig. 1.

Fig. 1 A PEMFC system.

Fig-5

Depending on the fuel, the fuel-processing unit is simple for hydrogen and complex for hydrocarbon fuel. Hydrocarbon fuel includes methane, methanol, ethanol, propane, naturalgas and gasoline etc. The core of fuel processing unit for hydrocarbon fuel is the reformer where the fuel is chemically converted to a hydrogen rich gas. There is a mismatch of the operating temperature between reformer unit and fuel cell stack. Heat generated from the fuel cell stack can be used for evaporation of fuel but is not high enough temperature for the reformer. Discharged gas from the anode side of the fuel cell containing residual hydrogen can be used for heating reformer. The loading of catalyst and the design of reformer far from optimized.

Air compressor and fan are used to transport and circulate the fuel and air. Efficient air compressor and fan are required to reduce the power consumption and to increase overall system efficiency. A quiet compressor is needed since a noisy air compressor defeats the silent feature of the fuel cell system.

Power conditioner plays a critical role in the fuel cell system. It buffers the fluctuation between power demand and fuel cell output power, converts DC power into AC power, and manages power consumption of individual component in the fuel cell system. For electrical or electronic industry to manage power with low current and high voltage is a common practice. However, the characteristic of fuel cell output power is low voltage and high current. This presents a unique problem for the power conditioner. The electrical-to-electrical energy conversion efficiency (about 85%) is less than satisfactory.

The fuel cell stack should be designed and optimized as part of the system, which includes the fuel reforming system and the balance of power plant. This will require the pinch analysis for optimizing the number and location of heat exchangers and also to match the temperatures of the fuel cell stack and fuel processor. Also the major challenging area is to integrate the reactors and heat exchangers for the fuel processing to reduce both the cost of the system and also the volume and weight requirements, which is very important for the transportation applications.

The Fuel :

The fuel required for the PEMFC is the hydrogen. It poses a number of challenges of hydrogen production, storage, safety and infrastructure, which are beyond the scope of the present coverage.

It provides a greatest challenge to find alternative fuels that would have the following characteristics:

(1) Direct electrochemical oxidation of fuel.

(2) Low toxicity and high chemical stability.

(3) Low corrosion of current collectors, catalysts, and membranes.

(4) High solubility in H_2O.

(5) High energy density.

(6) Fuel oxidation results in environmentally and fuel cell friendly products (e.g., CO_2).

Although methanol and ethanol are becoming potential candidates as the fuel for PEMFC, the reforming of alcohols or direct electrochemical oxidation of alcohol are far from satisfaction. The major challenges in searching new fuels are: Identify fuels that are attractive from a thermodynamic point of view (liquid state at STP, high volumetric energy density, environmentally friendly products, and miscible with water). Determine rate-determining steps in fuel oxidation reactions and seek means for its improvement, such as new catalysts, most effective particle size and distribution.

VI.PERFORMANCE CURVES OF PEMFC

Three important efficiencies for the hydrogen/oxygen fuel cell are: Thermodynamic efficiency, electrochemical efficiency and the Fuel Utilization coefficient or factor. The thermodynamic efficiency is the ratio of ideal electric energy to the total chemical energy of hydrogen and oxygen. It is the portion of the chemical energy of the fuel, which theoretically is converted into electrical energy. Electrochemical efficiency is the ratio of actual electrical energy output from the cell to the ideal electrical energy output from the cell, at 100% fuel utilization. When the fuel flows through the anode, not all fuel is chemically reacted for energy conversion. Hence, we define a fuel utilization coefficient μ*f* as the actual fuel reacted to the fuel supplied on a mass flow rate basis. If .Hr is the heating value of all fuel components that are converted electrochemically (e.g., H2) and .Hc is the heating value of all fuels (e.g., including CH4 or CO), then åH = Hr/. Hc.

Thus when the fuel other than hydrogen is used in a H2/O2 fuel cell, the total efficiency is the multiplication of these four efficiencies, and is in the range of 30-50% for most fuel cells.

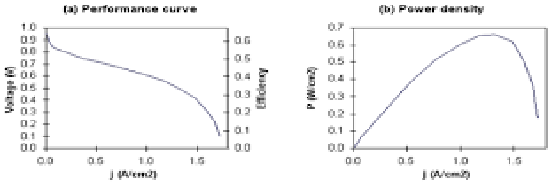

Fig-6

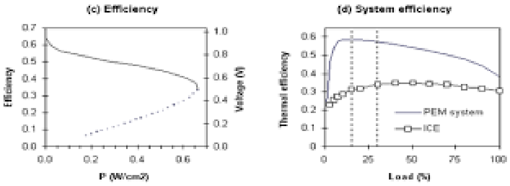

Fig-7

DRAW BACKS OF THE PRESENT MODELS

Ø The resultant low ph level water from fuel cells may corrode / ruin the road surface when the PEMFC is used in the automobile applications.

Ø The characteristic of fuel cell output power is low voltage and high current. This presents a unique problem for the power conditioner.

Ø Bipolar plates occupy 14-24% principle cost and 80% volume which should be overcome.

MAIN APPLICATIONS

- ✓ v In automobile sector, military, spacecraft and etc.
- ✓ v The development of fuel cells will be specially beneficial to India for supply of electrical energy to irrigation pumping sets in the villages and remote areas

NOTE: It is possible to create useful potentials of 100 to 1000 volts and power level of 1kw to 100mw by connecting number of cells in series and parallel combination.

VII.CONCLUSION

Starting with the current state of technology, the detailed R&D needs are presented in this paper for the cell, stack, system, fuel and fuel processing for the proton exchange membrane. The PEMFC is being developed for automotive propulsion, portable power and distributed power applications. Toyota Prius (commercialized suv vehicle using PEMFC) is the first step in vehicles segment released in commercial market utilizing the fuel cell technology. At present, these fuel cells have gone through demonstration projects for performance levels and anticipated improvements. The major issues are the cost/kW, durability and reliability. Extensive efforts are being devoted to improve the performance with less costly materials, lower material content, more simplified systems/components, less number of parts, addressing transient and steady state performance issues, reducing the losses, etc. An extensive coverage is provided in this paper for R&D needs to address some of these issues.

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