Review on Hydrogen Operated Vehicles

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Abstract:-

Hydrogen can be the source of fuel that can transform our fossil fuel dependent economy into a more efficient and an environment friendly economy. Hydrogen in the form of gas can be used in both CI and SI engines to enhance combustion and reduce toxic emissions By considering the various aspects of fuel, hydrogen is expected as a best option when consider as a gaseous state fuel. It is identified as a best alternate fuel for internal combustion engines as well as power generation application, which can be produced easily by means of various processes.. But certain difficulties limit its use in internal combustion engines which prompts us to tap into fuel cell technology or hybrid technology to achieve efficient as well as an environment friendly engine. A new concept of Extended Range Electric Vehicle (EREV) based in a Fuel Cell Electric Vehicle has also been described in this paper as an improvement to the currently implemented series hybrid technology. A new concept of Extended Range Electric Vehicle (EREV) based in a Fuel Cell Electric Vehicle has also been described in this paper as an improvement to the currently implemented series hybrid technology. The objective is that these vehicles can be presently used until the development of an electric and/or hydrogen recharge/refuel network allows being useful with the current status.

Keywords:- FCEV- Fuel Cell Electric Vehicle, EREV- Extended Range Electric Vehicle, ERFCEV- Extended Range Fuel Cell Electric Vehicle, BEV- Battery Electric Vehicle

1. Introduction:-

Increase in energy demand and pollution levels and the rapid depletion of current resources have led researchers to tap into new modes of fuels as an alternative to the current combustion exhaustible fossil fuels. Hydrogen is been looked into as the next fuel or a suitable alternative source to replace fossil fuels. Hydrogen fuel could be a emissions-free transportation fuel to transform our fossil fuel dependent economy. It can be a clean alternative fuel producing insignificant greenhouse emissions. Hydrogen gas can be used in traditional S.I and C.I engines. It can also be used in polymer electrolyte membrane (PEM) for greater efficiency (also known as fuel cells).

- **Advantages:-**
  Hydrogen has a high energy yield. It can be produced from primary energy sources. It has a wide flammability range and high diffusivity. It is a versatile fuel.Water vapor being the only principal exhaust product along with NOX; hydrogen can be termed as an environment friendly or green fuel.

- **Limitations:-**
  It has low density and as a result, low ignition energy. It is up to a certain extent an expensive fuel to produce as it is not found free in nature. As mentioned earlier hydrogen can be used in a traditional SI/CI engine or it can be used in a fuel cell vehicle as the sole operating fuel.

2. Various Methods to Produce Hydrogen:-

Hydrogen can be produced using various methods that have been described below..The different methods are steam reforming of methane gas, gasification, electrolysis of water and solar hydrogen system.[1]

2.1 Steam reforming of methane gas:-

- **CH4+H20 ⇨ CO2+3H2[5]**

This is currently the major source of hydrogen production. Steam reforming takes place in presence of nickel catalyst and at 700-1100 degree centigrade.

2.2 Hydrogen from coal (gasification):-

- **Coal+H2O+O2 ⇨ yngas [5]**
- **Syngas=H2+CO2+CO+CH4[5]**

Gasification is the process that converts carbonaceous fuel based carbon material into hydrogen, carbon dioxide and carbon monoxide.

2.3. Electrolysis of water.-

- **2H20 ⇨ 2H2+O2 [5]**

Electrolysis of water is the decomposition of water (H_2O) into oxygen (O_2) and hydrogen gas (H_2) due to an electric current being passed through the water.

2.4. Solar hydrogen system:-

- **2H20 ⇨ 2H2+O2 [5]**

A solar powered electrolyzer is used to convert water into hydrogen and oxygen which is used to produce electricity in a fuel cell.

3. Hydrogen Powered ICE:-

Researchers have carried out tests on combustion engine using hydrogen fuels. In this case tests were carried out on a multi-cylinder spark ignition engine with an electronically controlled port fuel injection system. The H2O2 mixture and gasoline were separately introduced into the intake manifold. A schematic diagram of the hydrogen line used by the researchers is shown in Fig. 1. The H2-O2 mixture was delivered into the engine with an additional fuel supplement system and a pressure regulator was used to reduce the pressure of the H2-O2 gas mixture produced by the electrolyser. The H2-O2 gas mixture was sent through a bubbler before being fed to the engine to prevent backfires in the engine. A relief valve was used to prevent overpressure, and a second pressure regulator was installed to regulate line pressure in the system. A thermal mass flow meter was used to measure flow rate. A rotameter was also used to check the hydrogen fuel flow rate against the thermal mass-flow meter. A buffer tank was installed between the flow meters and engine to reduce H2-O2 mixture flow fluctuations. A check valve and a flame arrestor were used before the engine intake manifold to prevent backfiring. No modification was made to the

original ECU of the test engine as self-developed ECU was used by the researchers to trigger the hydrogen injectors. The flow rates of injectors were determined according to the signal length with a series of preliminary tests. A power supply with constant current capability was used to control the current and the voltage of the electrolyser.

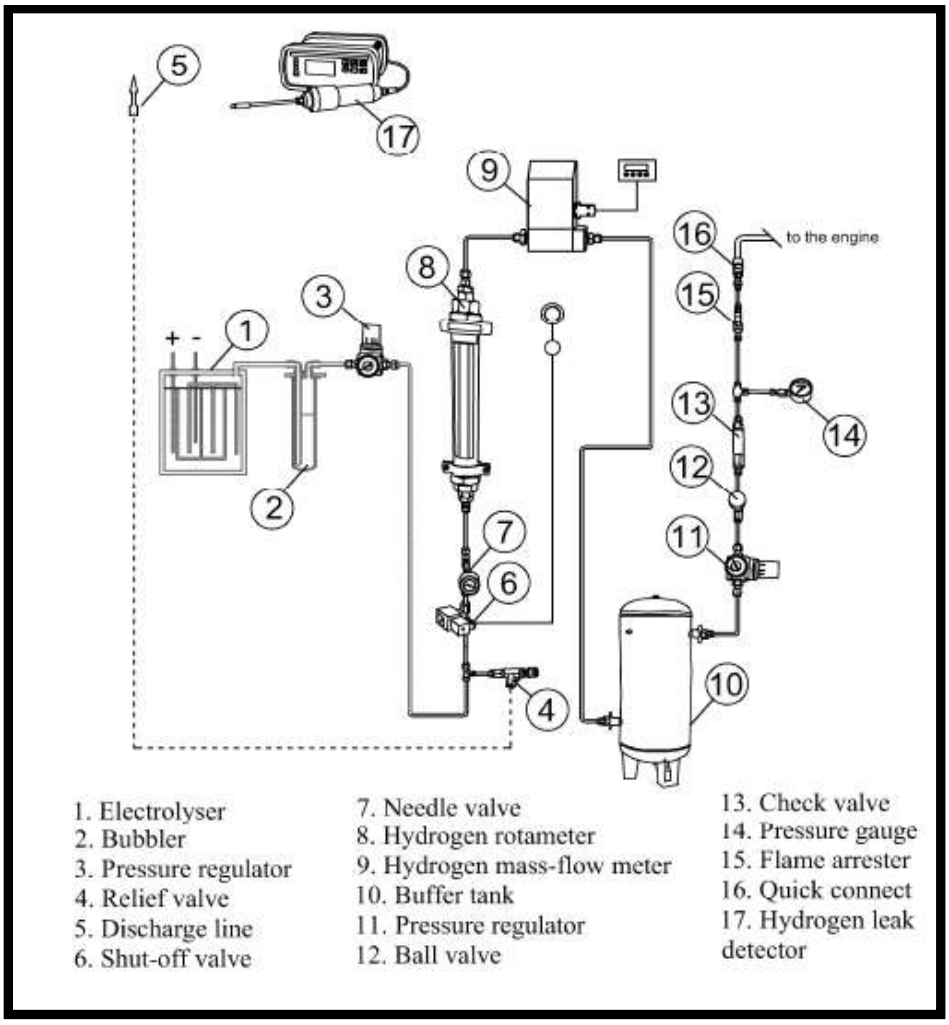

Fig 1: Schematic Diagram of Hydrogen ICE [3]

3.1 Observations:-

The following parameters were considered during the tests conducted by the researchers. The brake torque, brake power, BSEC, NOX, THC and CO measurements were acquired with a data acquisition system. [3]

3.1.1 Brake Specific Energy Consumption:-

It is the amount of energy consumed per kilowatt of power produced by the engine. The graph shows that adding a small amount H2O2 decreases BSEC regardless of engine speed.

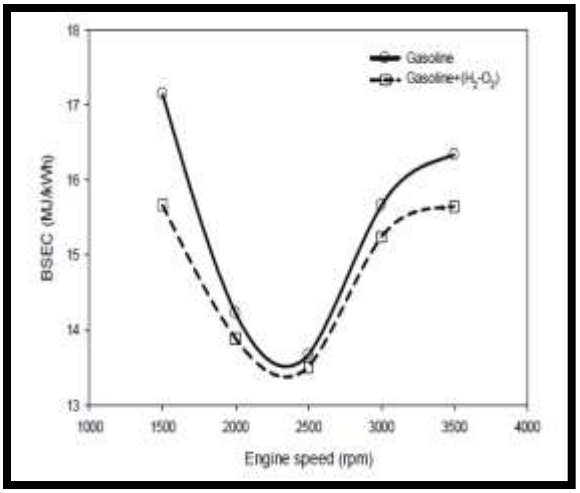

Fig 2:-Variation of BSEC vs. Engine Speed [3]

This happens because the flame speed of hydrogen is five times larger than hydrogen and as a result it leads to shorter burning duration which leads to lesser energy usage by the engine.The shorter burning duration and wider flammability range of the hydrogen gasoline mixture lead to higher combustion efficiency.

3.1.2 Reduction in emissions:-

As shown in the graphs, THC emissions are reduced as a gasoline hydrogen mixture can be more completely burnt due to the formation of OH radicals and shorter quenching distance of hydrogen fuel.CO emissions are also reduced as shown in the graph below. Emissions such as smoke and soot are also reduced. But as the graphs suggest, NOX emissions increase due to the high temperatures created in the engines and due to the availability of more amount of oxygen.The quenching distance of hydrogen is one third of gasolione and as a result it is burnt more closer to the cylinder walls.

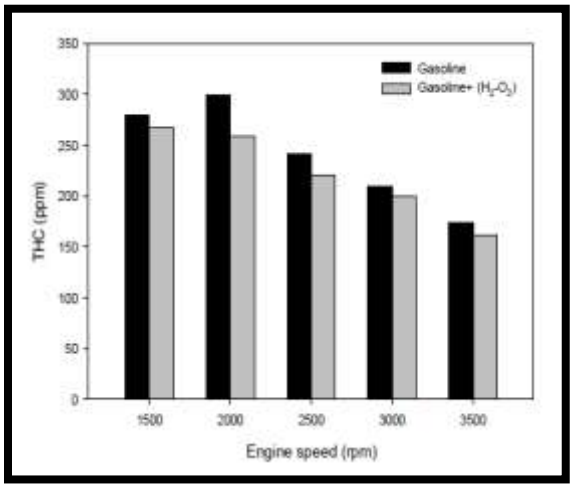

Fig 3:-Variation of THC vs. Engine Speed [3]

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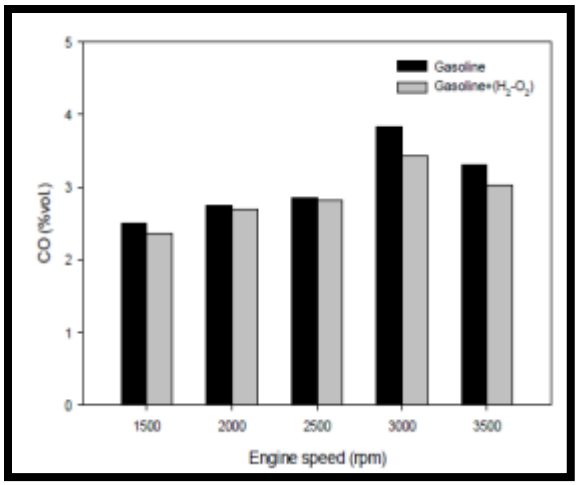

Fig 4:-Variation of CO vs. Engine Speed [3]

CO emissions are reduced as there are no traces of carbon in hydrogen fuel. Traces of carbon monoxide and carbon dioxide can be present in the exhaust gas due to seeped oil burning in the combustion chamber.

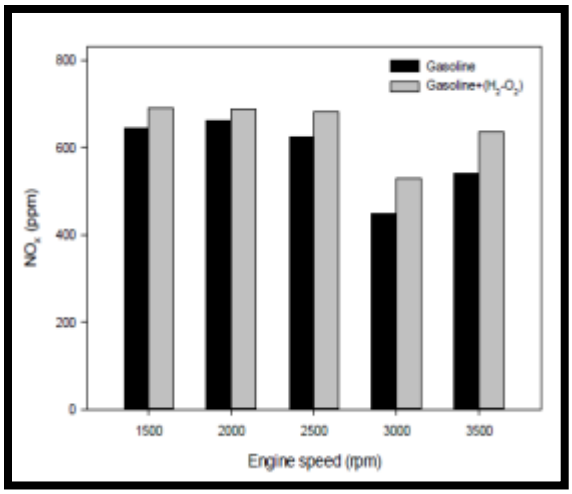

Fig 5:-Variation of NOX vs. Engine Speed [3]

Peak cylinder pressure and bulk cylinder temperature were increased with hydrogen addition. High temperature and more available oxygen in the charge may cause NOx emissions to rise. Higher flame temperature and speed of hydrogen combustion causes higher local in cylinder temperatures and a larger amount of NOx emissions.

4. Disadvantages of Hydrogen ICE:-

Hydrogen in an ICE will be used in an engine giving it efficiency no better than gasoline or around 15% at the wheels. It has low knock resistance in practice due to its low ignition energy and extremely high flame speed. Under the high pressure and temperature conditions in an engine, nitrogen and oxygen atoms in the air react to form various nitrogen oxides, collectively known as NOX. Hydrogen is pretty flammable as it has risks when it comes to malfunctions and accident safety. Storage of hydrogen is also another major issue as there are no provisions currently provided for the safe storage of hydrogen.

5. Hydrogen Fuel Cell Electric Vehicle:-

Fuel cell is a device in which electrochemical reaction takes place between Hydrogen and Oxygen. The main components of a fuel cell include an anode, a cathode and an electrolyte. In presence of an electrolyte, the fuel ions i.e. Hydrogen ions react with the Oxygen ions to produce electricity, water vapor and heat. A fuel cell generally produces 0.7 V and therefore, a stack of fuel cells is used in order to generate the required amount of electricity.

The reactions involved in a fuel cell are as follows [6]:

- Anode side (an oxidation reaction):
  $2H_2 \Rightarrow 4H^+ + 4e^-$
- Cathode side (a reduction reaction):
  $O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$
- Net reaction (the "redox" reaction):
  $2H_2 + O_2 \Rightarrow 2H_2O$

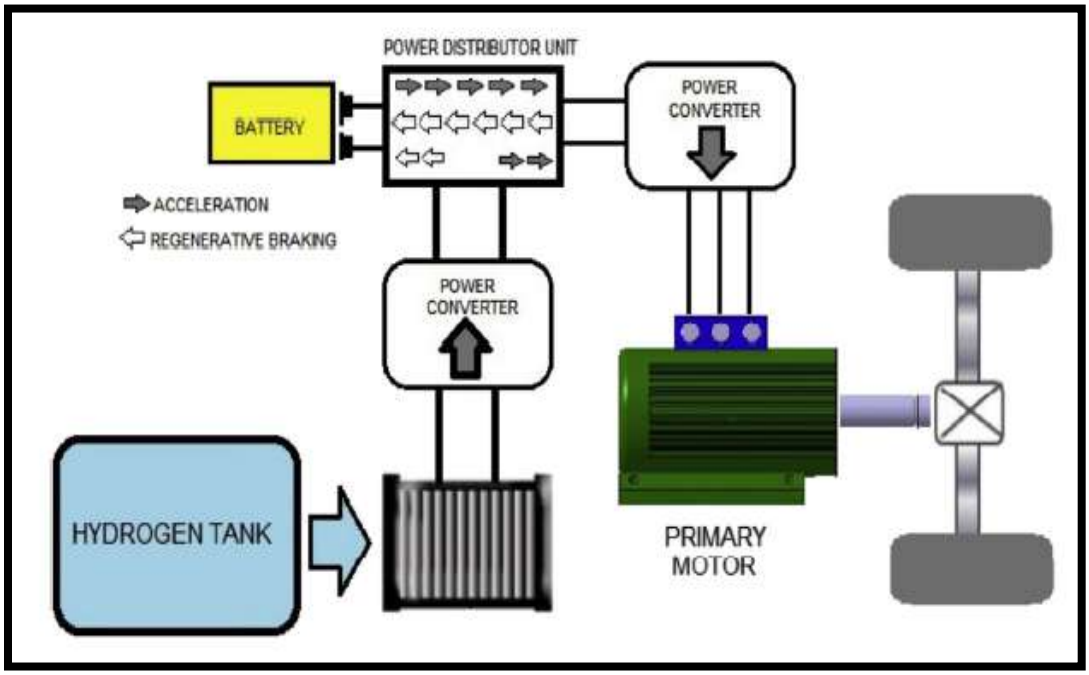

Fig 6:-Schematic of FCEV [4]

Vehicles use the fuel cell as a generator to power the engine. Like electric vehicles, a FCEV uses a fuel cell as its primary energy source. Energy flow controlled is by a Power Electronic Distributor Unit. It decides the direction of flow of energy in a fuel cell. During acceleration, the PDU uses the energy produced by fuel cells to meet the demand of the engine. In case of braking, PDU manages the regenerative braking by switching the motor to operate in reverse and thus the recovered electricity can then be stored in the battery. Currently, Honda Clarity and Hyundai Tuscon use this technology.

5.1 Advantages:-

Fuel cell vehicles are more efficient compared to any other conventional ICE. The tail pipe emissions of these vehicles contain only the water vapor and hence are non-polluting vehicles. As these engines operate silently, they help to keep sound pollution in check

5.2 Limitations:-

Storing hydrogen under high pressure is a risky affair and may prove fatal in case of collisions. Fuel refilling stations equipped with the sophisticated handling capability are required which have not been commissioned.

6. Extended Range Electric Vehicle:-

There are two main types of Plug in Hybrid Electric Vehicles [4]:-

6.1. Parallel Hybrids-In this type of hybrids, both the electric motor and combustion engines are used to power the wheels. A battery is used to power the electric motor and fuel is used for the combustion engine. Toyota Prius uses this technology,

6.2 Series Hybrids-These are known as the extended range electric vehicles in which the electric motor is coupled to the wheels and the combustion engine is used for the purpose of charging the battery.

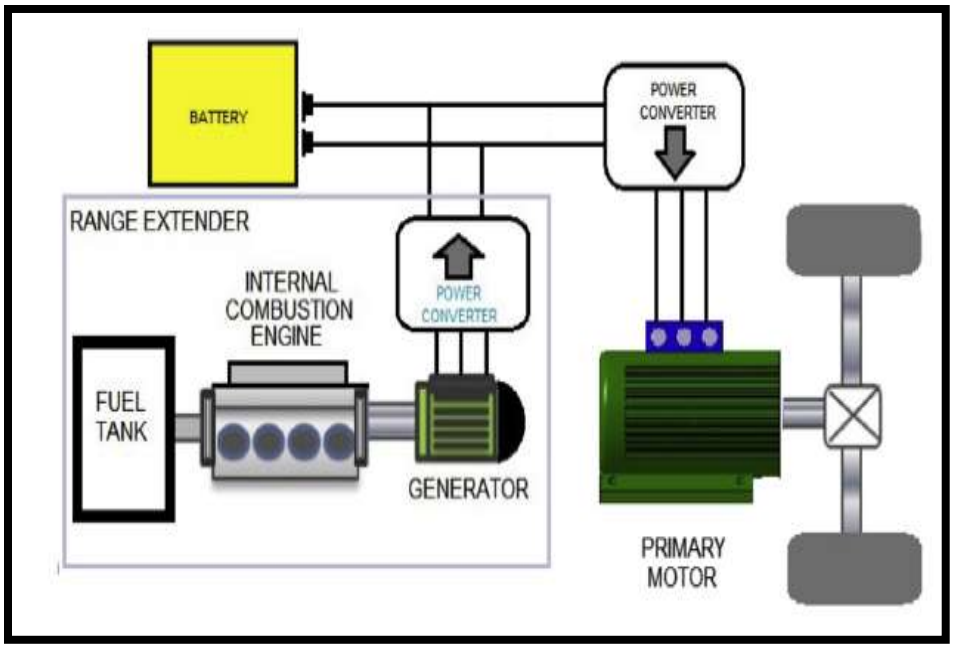

Fig 7:-Schematic of EREV [4]

As shown in the figure, the schematic is same as hydrogen FCEV only difference being the use of fuel tank instead of hydrogen fuel cell. These vehicles have a pure electric battery range of around 40 miles before the vehicle switches to the range-extender mode to continue the journey without any compromise in range.BMW i3 and Hyundai ix35 are the vehicles using this technology.

7. Extended Range Fuel Cell Electric Vehicle [4]:-

Researchers have proposed a concept wherein, in a series hybrid vehicle instead of a combustion engine, hydrogen fuel can be used. As shown in the schematic diagram these engines combine the working of a hydrogen FCEV and EREV.A battery is used to run the vehicle along with a hydrogen tank to recharge the batteries. Electric all-wheel system enables the vehicle to drive purely on electric power as priority with a fully charged battery. If the charge level is reduced, the fuel-cell switches itself on to recharge the battery and thus to increase the absolute range. Magna and Toyota Mirai are the vehicles using this technology.

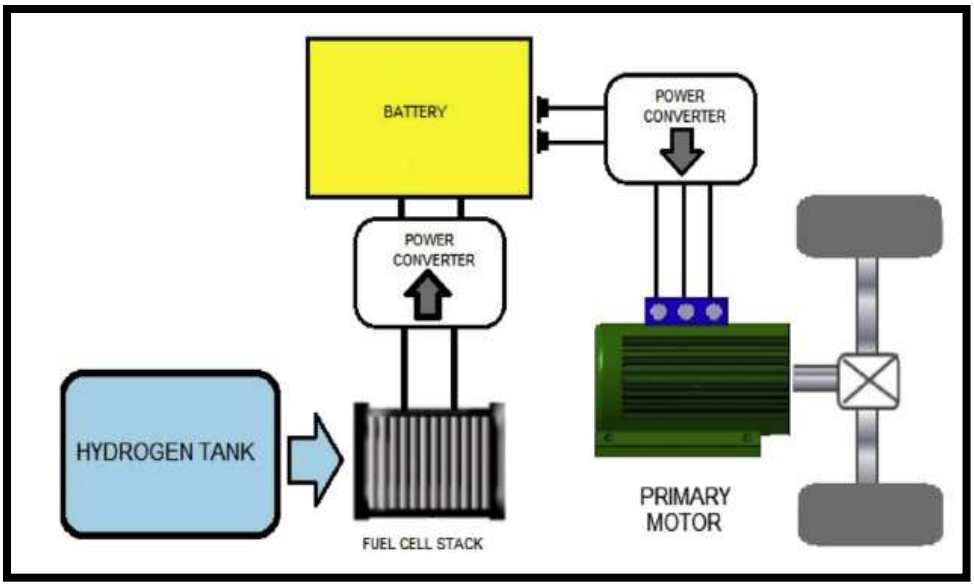

Fig 8:-Plug in FC-EREV Power Train [4]

8. Conclusion:-

As the above given extract suggests that hydrogen operated combustion engines will certainly provide more efficiency compared to the conventional gasoline operated engines and can be considered as an environment friendly option to them. The emissions of THC and CO are reduced by hydrogen addition but NOX emissions are increased due to higher cylinder temperatures. This coupled with accident safety and storage problems has prompted researchers to tap into fuel cell vehicles and the hybrid electric vehicles. The use of fuel cell technology in vehicles faces certain obstacles in the form of storage of hydrogen and the availability of the required infrastructure which is far from being available currently. Thus, the hydrogen operated battery vehicles or the hybrid vehicles seem to be a more feasible solution in the current scenario. The fuel cell extended range electric vehicle is a technology that can bridge the gap between the available infrastructure, an environment friendly and an efficient engine.

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