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1 Introduction

The project proposal for "Development and demonstration of hydrogen fuelled three wheeler vehicles in New Delhi" is very relevant in the context of the emerging energy-environment scenario in India. Most of the recent steps to bring down the pollution level in the cities of India have been very effective. The route of alternative gaseous fuel utilization such as Compressed Natural Gas (CNG) has shown remarkable results. The project activities aim at introducing the most environmentally friendly gaseous fuel, hydrogen, so as to drastically reduce the high levels of pollutants present in the ambient air. Furthermore hydrogen operated three wheelers will be able to send the signal in favour of hydrogen as the most environmentally friendly alternative transportation fuel. The three-wheelers have been chosen for this project as they represent a common mode of affordable public transport in India. It is proposed to operate a fleet of 15 three-wheelers (3W) vehicles powered by hydrogen in the site of New Delhi.

The project consortium is composed by:

1. UNIDO-ICHET who is providing funding to the project;
2. Indian Institute of Technology (IIT) of Delhi, the technical coordinator and expert in the engines conversion to hydrogen fuel;
3. Mahindra and Mahindra (M&M) who is supplying the vehicles fleet;
4. Air Products who is supplying the refilling facility;
5. UNIDO regional office in India, who is facilitating the on field operation.

Demonstration of developed concept on full hydrogen operation of Spark Ignition (SI) engine in small vehicles (three-wheelers) is the most innovative approach of the present proposal. The concept has already been developed and it is proposed to employ a fleet of such vehicles to study performance and exhaust emission characteristics of the vehicle within an exhibition area (Pragati Maidan) in New Delhi, India. Pragati Maidan offers 62,000 sq.m of covered exhibition space in sixteen conference and convention halls for hosting workshops, symposia, seminars and trade meetings. ITPO (India Trade Promotion Organisation) manages the exhibition complex.

Demonstrating hydrogen technology to face vehicle emission is one of the key aspects of this project. Such a study would bring out glaringly the ample benefits of hydrogen operation over that of conventional three wheelers.

Obnoxious pollutants such as carbon monoxide, carbon oxide, un-burnt hydrocarbons, oxides of sulphur, particulates will be absent in the exhaust of the vehicle. Then, by operating

the fleet in an internationally reputed tourist spot in New Delhi, the project will send a positive signal to other South Asian countries where three wheelers are also used for public transportation. A hydrogen refuelling infrastructure will be set up on site.

Pragati Maidan is India's only world-class exhibition complex.

2 Technical Description of 3W Conversion

M&M and IIT jointly developed a hydrogen engine system and M&M later developed a commercially viable three wheeler called as “HY Alfa”. This vehicle is the first of its kind in India and abroad running with compressed hydrogen gas.

The existing CNG operated three wheeler was modified for hydrogen operation and extensive experiments have been conducted to optimize the engine. Based on IIT recommendations, M&M had developed a hydrogen operated three wheeler for passenger and cargo version use. However these vehicles have been re-optimized to meet the performance and emission norms of Bharat Stage IV (BS-IV) Indian emission standard (which corresponds to EURO 4 norm of EU). This process includes

1. Initial Engine Testing
2. Recalibration of ECU and fuel injection system
3. Optimization of the engine for performance and emission
4. Integration of hydrogen storage system, fuel supply system and safety system in the vehicle for field demonstration.

The vehicle is designed ideally to suit city driving with zero carbon based emission. The NOx emission meets BS-IV target thanks to ECU controlled fuel injection and ignition.

Table 1: Engine Specification & Performance.

Engine Specification & Performance	
Type	**4 stroke**
Bore * Stroke	86*68
No Cylinders	One
Cooling Method	Air Cooled
Max Power	4.8kW @ 3600 RPM
Max Torque	13 Nm @ 2000-2200 RPM
Capacity of the engine	395 CC
Pay load	3+1
Gross vehicle weight	850 Kg
Fuel consumption	95 Km /Kg

The Engine Control Module (ECM) is a programmable microcontroller based device. It takes signals from different sensors (position and MAP Sensor) and decides the injection and ignition timing and duration of injection at different operating conditions.

ECM is programmed with open loop control strategy with inbuilt map control for A/F ratio range. This is a patented module specific to the Hydrogen operated 3-Wheeler Hy Alfa. The

ECU is also protected to adopt close loop control strategy which needs remapping and optimization.

The following sensors are used to operate the engine on the open loop control strategy

1. Engine Speed or Crank Position sensor: Crank position sensor is mounted on the flywheel to measure engine speed as well as the crank position. It is an inductive type pick up sensor.
2. Phase sensor: It is mounted on Cam Shaft of the engine and works on Hall Effect principle. Whenever lob of camshaft comes in front of the sensor a signal is generated. Based on this signal piston position is decided through the position of the generated signal. In this way start of injection can be varied based on this signal.
3. Temperature and Manifold Pressure Sensor (TMAP): This sensor measures absolute pressure in the intake of the engine which is correlated to measure load of the engine. We know that when there is increase in load on engine, manifold vacuum decreases and vice versa. MAP sensor senses this vacuum.

The injector is specially made for Hydrogen fuel and it is produced from a specialised supplier. The flow rate is chosen as per the engine requirement. The injector quantity is controlled by modulating the pulse width which is controlled by the ECU map.

Table 2: Comparison between HyAlfa Load Carrier and CNG Alfa passenger vehicle speed.

	3 person sitting	**Loaded**	**Unloaded**
	HyAlfa Load Carrier	CNG Alfa Passenger	
top speed(kmph)	36	52	57

Table 3: Comparison between CNG and hydrogen engines data.

CNG			**Hydrogen**		
Engine Speed	**Torque**	**Power**	**Engine Speed**	**Torque**	**Power**
RPM	Nm	kW	RPM	Nm	kW
1200				12.11	1.56
1600	18.6	3.1	1200	13.05	2.18
1800	18.5	3.5	1600		
2000	18.2	3.8	2000	13	2.73
2200	18.4	4.3	2400		
2400	18.6	4.7		12.41	3.04

The improvement of the existing system is oriented towards the adoption of higher compression ratio to improve thermal efficiency. The above comparison shows a power loss around 30% for hydrogen operated vehicle with a compression ratio of 8.5. To increase the power the compression ratio of the engine has to be also increased. Hydrogen is having higher auto-ignition temperature, so compression ratio can be increased without any abnormal combustion.

3 Hydrogen Storage and Supply System

Concerning safety issues appropriate hydrogen sensors, valves and arrestors are mounted to prevent the storage system form detonation and flame propagation risks.

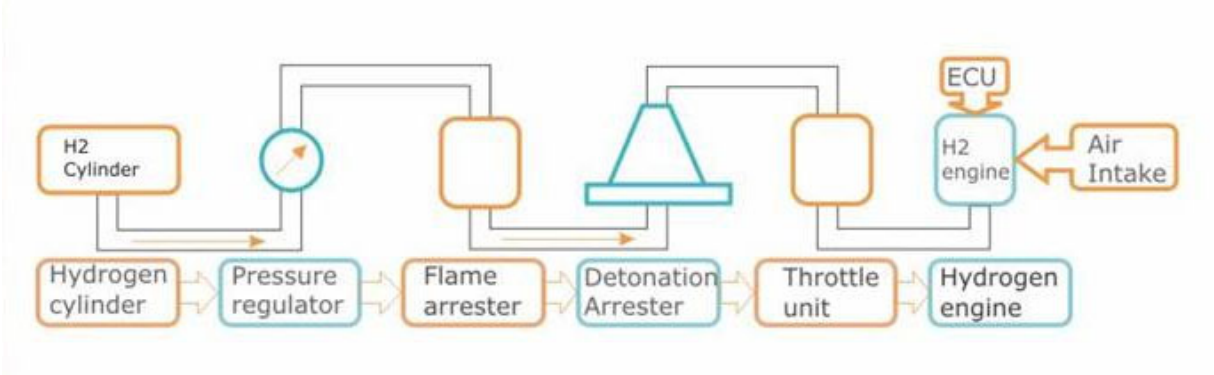

Figure 1: Hydrogen storage and safety system.

Conversion system is a manifold injection system which injects metered quantity of gas inside the manifold. Backfire is very prominent in hydrogen engine because it requires very small energy to ignite. In order to avoid back fire timed manifold type of injection has been chosen.

For safety purposes one hydrogen sensor is also integrated into the conversion system. A sensor is installed in the hydrogen cylinder compartment. As soon as the detector detects the hydrogen leakage ECM cut the fuel supply to the injector by relieving the gas solenoid plunger and blowing an alarm to the driver cabinet.

In case of backfire there is a chance for flame front to propagate through injector to cylinder. To quench the flame before it reaches the cylinder a flame arrestor has been installed between the cylinder and injector. Maximum working pressure of flame arrestor is 9 bar. It quenches the flame as well as acts as a NRV (Non Return Valve) device. This spring loaded NRV prevents slow or sudden reverse flow forming an explosive mixture in the gas supply. In addition to this, a manual shut off valve is utilised (Quarter Turn Valve). In case of any problem with the solenoid or regulator manually the fuel supply can be switched to a shut off position by manual shut off valve.

4 Field Testing and Evaluation

The vehicles would run for approximately 40 km per day. However the usage envisaged for the passenger vehicles is up to 8 hours a day and up to 10 hours for the goods vehicles. During the on field testing all the main parameters of the vehicles will be monitored in order to carry out a specific energy and environmental analysis of the hydrogen fleet based on real data. A CAN BUS communication protocol will be set up in order to download onboard data and post-process them. Furthermore the on field data will also enable to deepen design process, running costs and thus investment costs.

5 Conclusions and Future Developments

India has demonstrated to be one of the main candidates to take part in the hydrogen drive. First of all it is the only developing country featuring a Ministry of New and Renewable Energy (MNRE). Then a set of important initiatives have been undertaken:

- In 2003 a National Hydrogen Energy Board has been set up under MNRE;
- in 2007 a Hydrogen Roadmap has been prepared;
- green Initiative for Future Transport (GIFT), one million hydrogen fueled vehicles on the road by 2020;
- Green Initiative for Power Generation (GIP): 1000 MW of H2 powered ICEs, gas turbines and high temp fuel cells (FC).

Within this context a recent order for 40,000 FC-based UPS units for telecomunication has been placed. Due to the country size these initiatives carry a high potential to generate a real market and make India a hydrogen worldwide leader. Only in Delhi more than 50,000 CNG three-wheelers are circulating as Diesel fuel is banned from Delhi's area. Starting from the first of April 2010 all two and three-wheelers in India have to comply with BS III (EURO 3) emission norm whose emission limits in g/km are given in the following table.

Table 4: EURO 3 and EURO 4 emission standards.

Norm	CO	THC	NOx	HC+NOx	PM
EURO 3 Diesel	0.64		0.50	0.56	0.05
EURO3 gasoline	2.3	0.2	0.15	-	-
EURO 4	0.5		0.25	0.3	0.025
EURO4 gasoline	1.0	0.1	0.08		-

The environmental benefits related to the introduction of hydrogen fleets in comparison to conventional vehicles are then significant as regards the carbon based emission. With special reference to CO2 emissions the reduction gained in the passage from gasoline to CNG three-wheelers was around 12% (from 105 to 94 g/km). Hydrogen introduction will lead to completely eliminate this greenhouse gas production. Also NOx, thanks to the upgraded ECU, will be kept within EURO 4 limits (see table 4). Fleet applications suit very well hydrogen as a fuel in order to bypass the lack of refuelling infrastructures on road. In fact since the mission is known, the overall consumption of a fleet can be assessed in advance and the relative refuelling designed on purpose. Due to the considering number of such vehicles circulating in Delhi's area (50,000) and in the rest of India, it is evident that the hydrogen introduction can make an important shift towards cleaner transport, bridging the path to FC applications and zero emissions. Finally the ultimate aim of the project is to catalyse partnerships from private and public investors in order to continue and improve the fleet operation well beyond the end of ICHET funding (end of 2010) and establish a permanent transport service with a proper infrastructure. Three-wheelers are a popular mean of transport not only in India but also in other Asian countries, hence the success of the application of such hydrogen fleet has a big value also in light of its replication potential.

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