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Design hybrid system and component selection for Samand vehicle with battery and fuel cell propulsion

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ABSTRACT
Energy crisis and environmental pollution problem especially in large cities had caused automakers replace internal combustion engine to hybrid vehicles. Zero-emission fuel cell hybrid vehicles have one of the options for achieving this goal. In this article, chassis of Samand vehicle is used for designing a fuel cell-battery hybrid vehicle. Equipment that needed for propulsion system have been selected. The vehicle is modeled in Simulink and simulated in several drive cycles in Advisor software. Results demonstrate that a new hybrid system that designed for Samand chassis has suitable fuel consumption and In addition, the results of the hybrid model are compared with that of IC engine models of the same vehicle in terms of dynamic property like grade ability and acceleration.
Key words: Samand hybrid vehicle, fuel cell, battery, Advisor software, vehicle design

INTRODUCTION

Environmental pollution and reduction of fossil fuel resources are such problems that endangered human future life. The results of studies show that the bulk of pollutants emitted into the atmosphere and amount of consumed fossil fuel,are caused by transportation and vehicles which internal combustion vehicles constitute major contribution of them. Excess growth of vehicles and increasing traffic and decreasing average speed of the vehicles in the cities have led to greatly increased in fuel consumption. Hybrid vehicles are one of the alternative options for conventional vehicles in the world[1]. In the last decade the use of fuel cell hybrid electric vehicles has been increased. This vehicle is one way to reduce pollution in industrial equipment, fossil fuel consumption and cost of the operation in transportation systems. Fuel cell is one of the new technologies in the production of electrical energy and convert chemical energy into electrical energy with high efficiency which is adapted to the environment and in that [2].

In recent decades, a number of automotive companies, including large corporations and various agencies have supported research on fuel cell technology for use in vehicles. Increasing concerns about environmental damages have created need for cleaner vehicles with less fuel consumption. The recent remarkable advances in the field of proton exchange membrane (PEM) fuel cell technology have caused the development of fuel cell vehicles. Several samples of fuel cell vehicles are developed by large companies. Fuel cell vehicles are essentially a vehicle with no pollution that help to overcome the distance limitations in electric battery vehicles (EVs). Several cooperation agreements are done between fuel cell developers, car manufacturers, oil companies and government organizations for developing commercial fuel cell vehicles until now. However, there are still major parameters for use fuel cell vehicles in large-scale that must be overcome.

A lot of automotive companies are trying to build and develop fuel cell hybrid vehicles. Wang et al built a light weight car called Ming Tao in 2005. This car had PEM fuel cell with 5 kW power and the pure efficiency was 30% [3]. Honda Company introduced his progress in fuel cell vehicle technology in 2009 by introducing new vehicle called Clarity. Honda Clarity has 100 kW output power and fuel cell efficiency is 52% in optimum operating conditions. This car has the capability to start in -30℃ [4]. In 2010, Hyundai Company presented two types of fuel cell vehicle in Tucson and Sportage platforms. In 2009, Daimler Company announced that tens of thousands of fuel cell vehicles will marketed until 2013. In this year, this Company built two fuel cell hybrid vehicle called Fcell and Fcell-Roadster [5]. Peugeot built the first model of these vehicles called Quark in 2004 and then introduced H2Origin-Fuel cell in 2008. Also the last model of General Motors Company is Hydrogen4 which is introduced in 2007. This car has 440 cells of fuel cell with the power of 93 kW and consumed 1.3 kg hydrogen for each hundred kilometers [6]. Figure (1) shows the components of the fuel cell battery vehicle. Fuel cell and battery supply the electric power for electric motor. A converter is on the way of the fuel cell to balance the produced voltage of the fuel cell and bus voltage. In the way of the battery also is bi-directional converter that help battery to receive the voltage for charging. Also an inverter is used to convert the DC voltage of the battery and fuel cell to AC input voltage of electric motor.

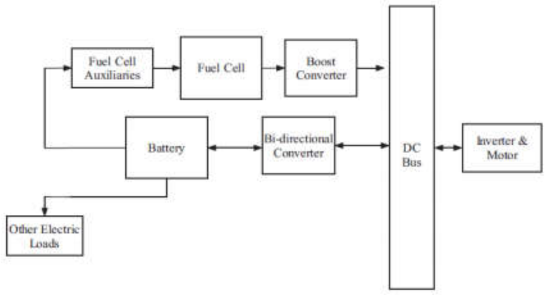


Fig.1 Battery and Fuel Cell Hybrid Vehicle Schematic

In this paper chassis of the Samand vehicle is used for design a new propulsion system with battery and fuel cell. All required components for hybrid system are selected and replaced to IC model. The vehicle will modeled in Simulink-MATLAB and simulated in 4 drive cycles in Advisor software.

Vehicle design

Vehicle equipment is designed Based on the characteristics of the typical vehicle and the conditions that vehicle meets in real time. Velocity and acceleration of the vehicle must considered for vehicle design. Specifications of the Samand chassis are used for design the vehicle dynamics. The movement behavior of a vehicle along its moving direction is completely determined by all the forces acting on it in this direction. Figure 2.1 shows the forces acting on a vehicle moving up a grade [7]. The tractive effort, F_t, in the contact area between the tires of the driven wheels and the road surface propels the vehicle forward. It is produced by the power plant torque and transferred through transmission and final drive to the drive wheels. While the vehicle is moving, there is resistance that tries to stop its movement. The resistance usually includes tire rolling resistance, aerodynamic drag, and uphill resistance. Therefore the dynamic equation of the vehicle is expressed by:

$$f_t = m_v a_t + f_a + f_r + f_g \quad (1)$$

$$f_a = 0/5 \ \rho_a A_f C_D v^2_{vehicle} \quad (2)$$

$$f_r = v_{vehicle} C_r m_v g \cos \alpha \quad (3)$$

$$f_g = m_v g \sin \alpha \quad (4)$$

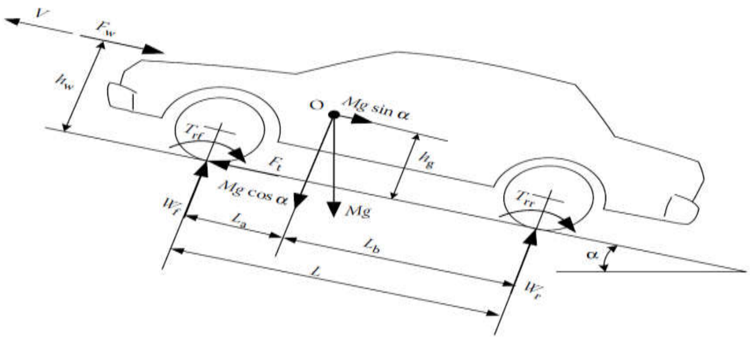


Fig.2 Forces acting on a vehicle moving uphill

Where ρ_a is air density, A_f is shape of the vehicle body, C_D is aerodynamic drag coefficient, $V_{vehicle}$ is vehicle velocity, C_r is rolling friction coefficient, ∝ is the road angle and m_V is the total mass of the vehicle. Table (1) shows the specifications of the Samand vehicle[8].

Table 1. Samand specifications

Cd =0/318	aerodynamic drag coefficient
Fr =0/0102	rolling friction coefficient
Af =1/97 m2	shape of the vehicle body
Rw =0/287 m	Dynamic rolling radius
Eff=92%	Gearbox and differential efficiency
M=901 kg	Weight of unchanged components

In order to calculate required power of the vehicle, three conditions are considered.These conditions are selected in such a way that the vehicle is close to the typical specifications of the Samand.

- Power required of the vehicle for 0 to 100 km/h acceleration time in 14s.
- Power required of the vehicle for moving in the zero angle road with 150 km/h constant speed.
- Power required of the vehicle for moving in the 5% angle road with 100 km/h constant speed.

According to Newton's second law, vehicle acceleration can be written as:

$$a = \frac{dv}{dt} = \frac{F_t - F_r - F_a}{m\delta} \quad (5)$$

Where δ is called rotational inertia factor that is assumed 1.08 [7]. Mass of the vehicle with respect to the 280 kg for four passengers, 350 kg for hybrid components and 901kg for unchanged components of the Samand vehicle is assumed 1530 kg. By assuming 90% for electric motor efficiency and 92 % for transmission system, power required for the electric motor in 14 s acceleration time is 63 kW. Approximate equation (6) can be used for second and third equation [7]:

$$P = Mg(F_r + grd)V + \frac{1}{2}\rho C_D A_f V^3 \quad (6)$$

Therefore 33.6 kW the power required of the second condition, and 33 kW the power required of the third equation, are obtained.

Vehicle components selection

Electric motor and Power resources of the vehicle (fuel cell and battery) are selected according to the power designed for vehicle. Table (2) shows the components that selected for the hybrid system of the Samand vehicle.Fuel cell provides 25 kW of the power. The remaining power of the motor is supplied by a lithium-polymer battery with 40 AH capacity. This battery with 65 cells can provides 45 kW power for hybrid system. As a result, total power of the fuel cell and battery can provides 63 kW for electric motor.

To select hydrogen storage tank of the vehicle, weight, pressure, tank size and material must be considered. Hydrogen fuel of the proposed hybrid vehicle can be used as hydrogen gas in pressurized tanks or liquid hydrogen in cryogenic tanks. It is better to use pressurized tanks due to having better safety. Table(3) shows the fuel consumption of the vehicle in different drive cycles. FTP drive cycle has the most rate of fuel consumption. Therefore, required fuel of the vehicle is obtained from simulating proposed vehicle in FTP drive cycle. It is assumed that vehicle can travel 400km with one tank. Therefore, the amount of hydrogen required for the vehicle is equals to:

45.1 (L/100 km) × 4 = 180(L/400 km) (7)

As a result, the tank should have a capacity of at least 180 liters of hydrogen gas.

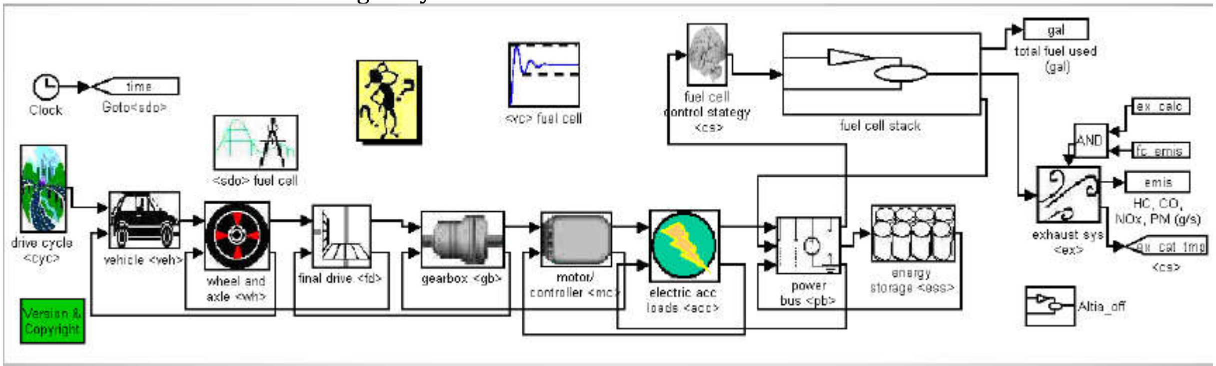
Table2.selected components for the proposed vehicle

Hybrid Vehicle Components	Manufacturer	model	specification
Fuel cell	Proton Motor	PM Module S 25	120 kg – 25 kW
Electric motor	Brusa	HSM1-6.17.12	220 Nm – 70 kW 51.5 kg
Battery	Brusa	DMC524	95 kg – 79 kW
Converter	Kokam	SLPB 100216216H	40 Ah – 65 cells 1.1 kg per cell
Inverter	Brusa	BDF624	40 kW – 10 kg
Hydrogen tank	Tuffshell	Type 4	883*350 mm

Modeling of Samand hybrid vehicle

The purpose of the modeling is to provide a virtual reality for testing designed control systems of the vehicle. More accurate model means that the results are closer to what happen in reality. Vehicle modeling is done in Advisor software. Advisor uses MATLAB/Simulink to create a model by graphically block diagrams. Figure (3) shows a hybrid vehicle model in Advisor.

Fig 3. Hybrid vehicle model in Advisor software



Samand hybrid vehicle model is also done based on the above model. Specifications of Samand vehicle and selected components also added to the Simulink model as MATLAB code. Figure (3) shows the model of hybrid vehicle in Advisor in order to understand its performance. Arrows shows the relation between parts. Blocks show the transmission elements of the vehicle that the data processing is done in there. Arrows that transfer data from left to right, like an arrow goes from differential block to the gearbox block, are part of the backward model that pass the demand torque, speed, force and mechanical and electrical power demand through the power transmission chain. Arrows who created recursive loop from right to left, are part of the forward model that transfer actual torque, speed, force, mechanical and electrical generated power to the back blocks. Each block models the relative part in the power transmission chain which may include efficiency calculation of the efficiency curve and the calculation of its losses.

Simulation and results

The proposed Samand vehicle is simulated in 4 standard driving cycles. UDDS cycle that has lots variation in speed,acceleration and deceleration and it is suitable for testing vehicle in urban road. HWFET that is suitable for testing vehicle in highways. FTP cycle that has a long dwell time (such as heavy traffic or red lights in intersections) and a combined cycle from UDDS,HWFET and FTP that testing the vehicle in a long time.The default controller of the Advisor software for series hybrid vehicle (PTC) is used for this vehicle.

Table 3. Fuel consumption of the proposed vehicle

	Driving cycle	UDDS	FTP	HWFET	UDDS+HWFET +FTP
Fuel consumption (L/100)	Hydrogen consumption	44.5	45.1	34.8	43.1
	Gasoline equivalent consumption	4.4	4.5	3.4	4.3

The results in table(3) indicates that the fuel consumption of the proposed hybrid vehicle is much lower than the typical Samand vehicle with internal combustion engine. Also this vehicle doesn't have pollution due to use of fuel cell with pure hydrogen. Fuel consumption is reduced in HWFET cycle due to constant vehicle speed and low power requirement in most of the time of the cycle

Table 4. Dynamic properties of the proposed vehicle

Acceleration time 0 to 100 km/h (s)	Geadeability at 90 km/h	Max speed (km/h)	Time in 0.4 km (s)	Distance in 5s (m)
11.6	15.4%	173.1	18	51

As shown in table (4), the acceleration of the vehicle has improved as compared to conventional Samand vehicle. This is due to the use of lithium polymer batteries with high energy density. Also it is evident that gradeability of the vehicle in 90 km/h is about 15% that satisfies the initial conditions of the vehicle design. Figure (4) shows State of Charge (SOC) of the battery during the cycles. Advisor software uses SOC correction with tolerance 0.005 between the final and initial SOC.

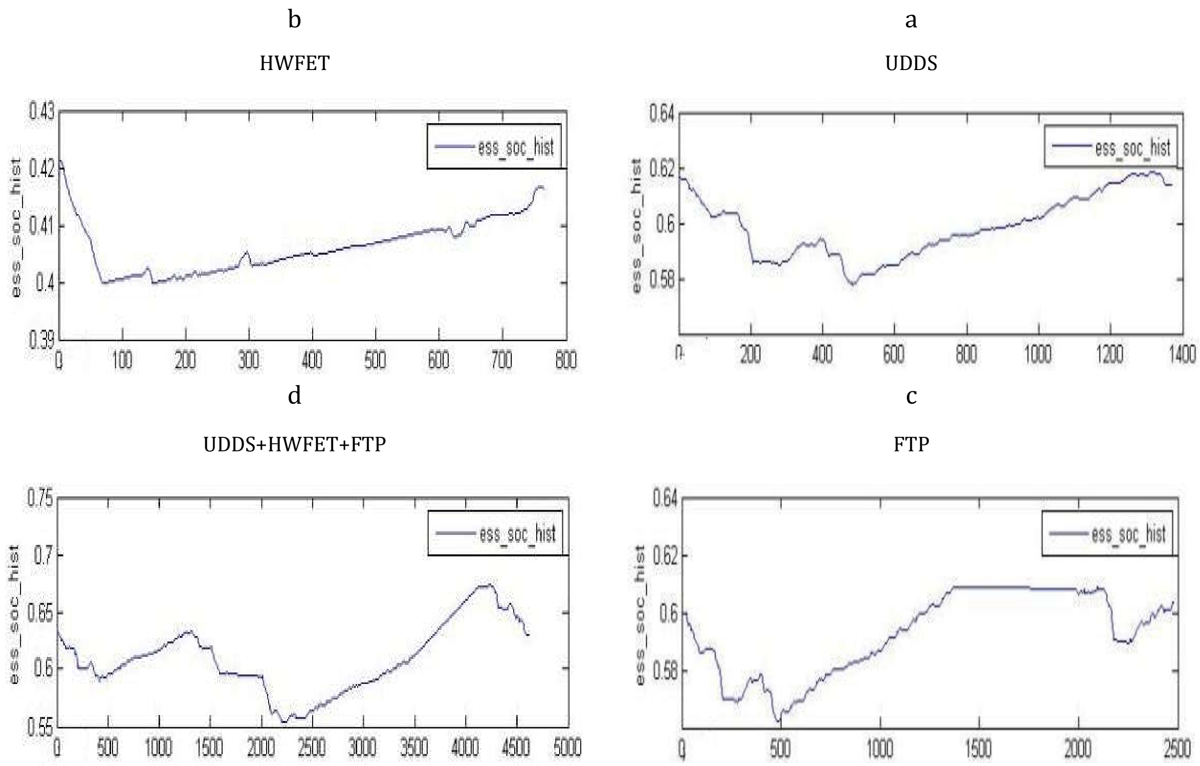


Fig.4 State of charge

Figure (4.a) shows that SOC changes of the battery is high. This is due to multiple brake and acceleration in UDDS cycle. In figure (4.b) changes of the battery drop at the beginning of the cycle, when the vehicle is in acceleration mode and in continue power consumption of the vehicle is less than the acceleration mode due to vehicle movement in highway and approximate constant vehicle speed. In this mode excess power of the fuel cell will be consumed for charging the battery. In figure (4.c), the vehicle is in stationary mode(like traffic or red lights in intersections) when charge of the battery is fixed. Also figure (4.d) shows the SOC of the battery in combined cycle. According to the changes in SOC of the battery it is observed when the vehicle is not in acceleration mode or has not maximum power and speed, battery can charge from power of the fuel cell.

Figure (4,5,6,7) indicates the power generation from battery and fuel cell in 4 driving cycles. It is observed that the battery power in negative when fuel cell wants to charge the battery. It means that battery is in charging mode. In braking mode of the vehicle, electric motor becomes generator to get the power of the braking from wheels and send it to charge the battery. This action can reduce the sending power from fuel cell to the battery and therefore it can reduce fuel consumption considerably.

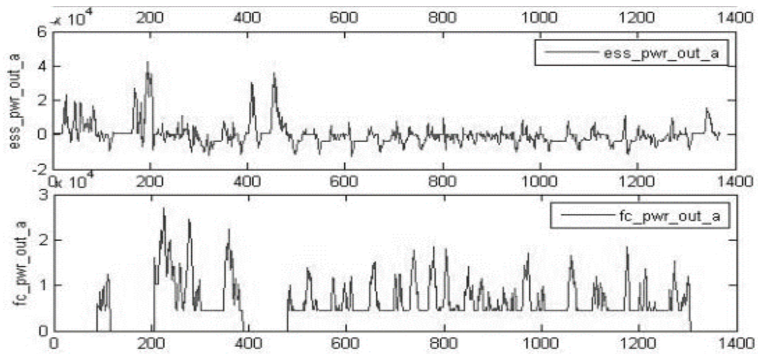


Fig.4 power generation from battery and fuel cell in UDDS cycle

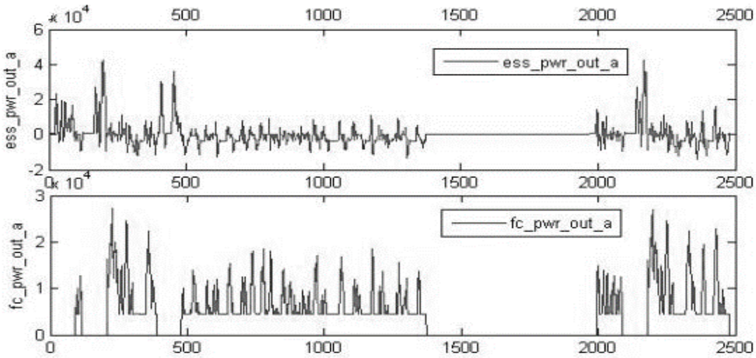


Fig.5 power generation from battery and fuel cell in FTP cycle

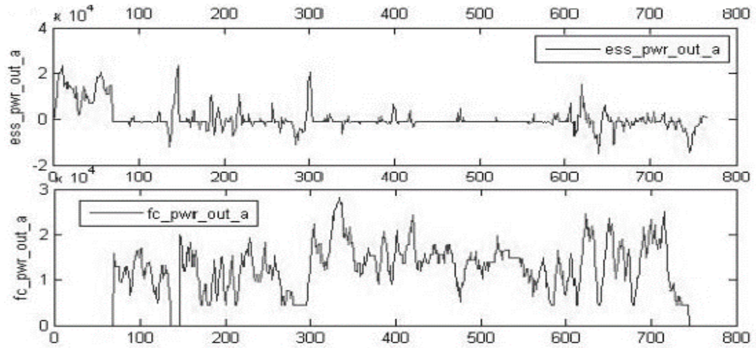


Fig.6 power generation from battery and fuel cell in HWFET cycle

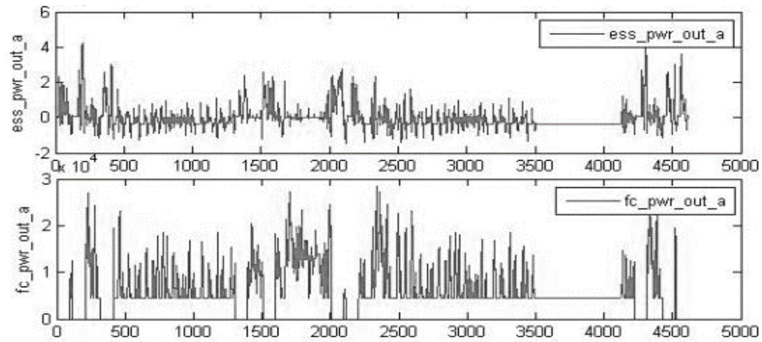


Fig.7 power generation from battery and fuel cell in UDDS+HWFET+FTP cycle

Conclusion

In recent years, it is anticipated that global energy demand and use of vehicles will increase naturally. In order to save energy, protect environment and improve quality of life, the kind of technology is needed that has required performance to supply global energy demand and skills to use in vehicles, homes and airports and that is enough clean to not harm the environment. In order to answer this needs, fuel celltechnology is one of the key recommendations. The proposed hybrid Samand vehicle in this paper shows that the fuel consumption of the Samand vehicle with battery and fuel cell hybrid system has about half of the fuel consumption in conventional Samand with internal combustion engine. Also this vehicle has ability to compete with conventional Samand in terms of acceleration and gradeability. Therefore, hybridization of the vehicles can meets the demands of the drivers in addition to an important reduction of environmental pollution.

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