Efficiency and Green House Emission Response of Different Vehicles Operating on Various Driving Cycles

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Abstract. In today's scenario, energy security and global warming are considered as vital parameters of concern. The use of large number of conventional vehicles on roads has caused serious environmental pollution and they consume considerable amount of energy resources. Thus solution lies in switching to cleaner and greener energy alternatives, such as electrical energy. In this paper, conventional, electric and hybrid electric vehicles are compared on the basis of efficiency and greenhouse gas emissions. For efficient comparison, three different cycles, namely, Manhattan, Urban Dynamometer Driving Schedule and Arterial, are chosen. The simulation and computer modelling is implemented using the Advanced vehicle simulator (ADVISOR) platform. When Electric vehicle is tested on three different types of driving cycles, it exhibits highest efficiency and no tail pipe emission as compared to other vehicles. Thus the use of Pure electric vehicle eliminates both the problem of depleting energy resources and environmental pollution.

Keywords—Electric vehicles, Conventional vehicles, Hybrid vehicles, ADVISOR, Driving cycle.

1. INTRODUCTION

Vehicle, the most important necessity of human life, is used to transport people or cargo. Automobile plays an incredible role in economic and social growth of any country. Conventional vehicles uses major portion of renewable energy resources like petroleum, diesel, gas etc., to drive their wheels but these resources are limited in nature. Moreover, it causes considerable pollution in the form of CO\textsubscript{2}, NO\textsubscript{x}, particles matter [1]. Resorting to electric energy is the best option to reduce CO\textsubscript{2}, NO\textsubscript{x}, Hydro Carbon(HC) emission, which is the prime culprit in global warming[2]. Over the past few decades, there is significant development in automobile industry [3]. Only Electric and Low emission hybrid vehicles can meet the outlined criterion of developing ultra-low emission automobiles as mentioned in the national regulations, which ensure a systematic and sustained development of low emission land vehicles. By 2035, almost 85% of all the vehicles introduced in the market will be electrical vehicles [4,5]. On broad terms, electrical vehicles are classified as Pure Electric vehicles (PEV) and Hybrid electric vehicles(HEV). The pure electric vehicle utilizes only one source of energy, electrical energy while hybrid electric vehicle uses the combination of two different power sources i.e, internal combustion engine and batteries. In this paper, a broad comparison between conventional, hybrid and pure electric vehicles are done on the basis of overall efficiency and CO\textsubscript{2}, NO\textsubscript{x}, HC emission. The simulation and computer modelling is implemented by using Advanced vehicle simulator (ADVISOR) tool from the DOE’s national Renewable energy laboratory [6]. The performance of pure electric, conventional IC engine and hybrid electric vehicles are compared in terms of efficiency and vehicle emission[7,8]. These performance parameters are evaluated on different driving cycles [9,10]. This paper is organized as: Section II explains the vehicle dynamics and driving cycle; Section III introduces ADVISOR, a simulating tool. Simulation is illustrated in Section IV followed by conclusions and result in Section V.

2. VEHICLE DYNAMICS AND DRIVING CYCLE

2.1 Vehicle Dynamics

Electric vehicle is the type of vehicle that utilizes only electrical energy to propel its wheels or uses battery to store energy. The most commonly used, conventional vehicle uses only internal combustion for its working while hybrid electric vehicle utilizes both internal combustion engine and battery to drive its wheel. The basic difference between conventional and electric vehicle lies in its power train system. The combustion engine in traditional vehicles is fuelled by fossil fuel whereas electric energy is the main source in electric vehicle and it mainly includes battery system, control system and motor system.
Figure 1. Vehicle dynamics diagram

The vehicle modelling is based on the vehicle dynamic diagram as shown in figure 1 and is derived from the basic equation of Newton’s Second Law, \( F = ma \).

This equation can be modified with some explicit forces acting on vehicles

\[
F = mg_C_{rr} + \frac{1}{2} \rho C_D AV^2 + ma + mgsin\theta
\]

(1)

Where, \( F \) = force required at the wheels of the vehicle, Newton
\( C_{rr} \) = coefficient of rolling resistance between tyres of vehicle and the surface of road.
\( m \) = mass of the vehicle, kg.
\( \rho \) = density of the ambient air, kg/m\(^3\)
\( C_D \) = coefficient of drag of the vehicle
\( A \) = area of cross section of the vehicle, m\(^2\)
\( v \) = velocity of the vehicle, m/s
\( a \) = acceleration of the vehicle, m/s\(^2\)
\( g \) = acceleration of gravity, m/s\(^2\)
\( \theta \) = angle of inclination between vehicle and road, degrees

The first term specifies the essential force required for overcoming the rolling resistance of the vehicle. This force remains constant in spite of increase or decrease of the vehicle speed. The second term denotes the drag force that the vehicle has to conquer at a certain speed. The drag force is proportional to the square of speed of the driving vehicle. Third term specifies the inertial mass of the vehicle. It has no effect under the constant-speed conditions and is non-zero only when the vehicle is decelerated/accelerated and the last term specifies the force required to propel the vehicle on a nonzero grade. Now the required torque, \( T \) (N-m) and angular velocity, \( \omega \) (radians per second) is calculated by using equations

\[
T = Fr
\]

(2)

\[
\omega = \frac{v}{r}
\]

(3)

Where \( v \) = linear velocity in m/s and \( r \) is the radius of wheel. The input angular velocity, \( W_{in} \) is calculated using the overall reduction ratio, \( R_x \) of the transmission. Compensating for the transmission efficiency, \( \eta_x \) as a function of torque-input speed, the input torque, \( T_{in} \) can be expressed as

\[
W_{in} = W_{out}R_x
\]

(4)

\[
T_{in} = \frac{\omega_{out}W_{out}}{R_x}
\]

(5)

The input power, \( P_{in} \) required from the vehicle voltage bus is calculated by using efficiency of inverter or motor at desired torque and speed

\[
P_{in} = \frac{\omega_{out}W_{out}}{\eta_m(\omega_{out}W_{out})}
\]

(6)

where \( \eta_m \) is efficiency of the motor and \( \eta_{in} \) is efficiency of the inverter. This power input is supplied either by batteries or auxiliary power units depending upon the type of vehicle used.

2.2 Driving cycle

The driving cycles are basically data point of speed (Km/hrs) versus time (seconds) that represent the particular driving sample. It is used to find out the performance of vehicle in terms of rate acceleration/deceleration, fuel consumption, emission, etc. A typical driving cycle curve is used for representing the progression of vehicle operating conditions; acceleration, steady state (const. speed) and deceleration for a given region, city or a country. To test the vehicle performance and to check
whether a design is appropriate for desired application or not, driving cycles are used. This results in reduction of expense on road test and save the fatigue and time of test engineers.

3. ADVANCED VEHICLE SIMULATOR (ADVISOR)

The modelling and simulation of vehicles are done in ADVISOR. It operates in MATLAB/Simulink environment as MATLAB is known for its modelling flexibility, visualization and optimization toolbox. In MATLAB files, vehicle data is provided and models are developed in Simulink. ADVISOR works in backward facing model, which requires no driver behaviour. It simply answers the question like how each component in vehicle configuration must perform in order to meet the desired trace and the force required to move the vehicle are directly calculated from the speed trace and then it is translated into torque. The driving pattern is set as input and force required to accelerate the vehicle is calculated and this force is converted into torque which is passed through the drive train until a tractive force is calculated. This calculation approach is carried backward, element by element, until the amount of energy or fuel required to meet the desired trace is calculated.

4. SIMULATION

In this paper, three different driving cycles were chosen for comparison, namely Manhattan, Urban Dynamometer Driving Schedule (UDDS) and Arterial. The speed-time characteristics of above mentioned driving cycles are as shown in figure 2. The Manhattan driving cycle is a low speed and frequent stops cycle. The UDDS driving cycle represents the city driving condition for light duty cycle testing whereas the arterial driving cycle computes fuel economy of the heavy duty vehicle.

![Speed time characteristics of Manhattan, UDDS, Arterial driving cycles](image)

Figure. 2.Speed time characteristics of Manhattan, UDDS, Arterial driving cycles

The Electrical, hybrid and conventional vehicle are simulated in ADVISOR platform. Table 1 represents various parameters associated with vehicles and its specifications

| PARAMETER       | SPECIFICATIONS |
|-----------------|----------------|
| Frontal Area    | 2.174 m²       |
| Mass of vehicle | 1368 kg        |
Aerodynamic drag coefficient 0.327
Overall gear ratio 6
Coefficient of rolling resistance 0.008
Type of motor Permanent magnet DC motor
Maximum torque 248 Nm
Battery type NiMH
Pack voltage 380 V
Capacity of battery 104Ah
Initial SOC 1
ICE power 50kw

The data flow in electric, conventional and hybrid vehicles are represented in the form of block diagrams shown in figure 3. The input to each block diagram is from drive cycle. The drive cycle block contain all the data of drive train components and it sends the desired speed trace to the next block i.e vehicle block. In each component model data is defined by the text files in the database. For example motor/control block contains all motor related data. The vehicle block has no drive train performance restrictions. It directly uses the desired trace for finding the average speed and force required over the time step. Now this information is passed to wheel/axle block which convert this linear speed and force into angular speed and torque using vehicle parameters. Depending upon the efficiency of the motor at any particular torque and angular speed, the input power required from the vehicle’s voltage bus is computed. This required power is supplied either by the batteries or by combination of both auxiliary power unit and batteries. Once this calculation work has been done, software ADVISOR updates fuel used state of charge (SOC) of battery, emission etc., and then moves to the next step.

Figure 3. Block diagram of the hybrid electric vehicle using ADVISOR

The vehicle emissions computed using ADVISOR for the three different types of vehicles are tabulated in Table 2. Three categories of vehicle emissions i.e Carbon Monoxide, Oxides of nitrogen (NOx) and hydrocarbons are studied and shown in tabular form. The graphical representation of these emissions for hybrid, electric and conventional vehicles are shown in figure 4.

| Greenhouse gas emissions(grams/mile) | Conventional Vehicle | Electric Vehicle | Hybrid Electric vehicle |
|-------------------------------------|----------------------|-----------------|------------------------|
| Oxides of Nitrogen (NOx)            | 1.89                 | 0               | 1.606                  |
| Hydrocarbons (HC)                   | 7.4                  | 0               | 6.57                   |
| Carbon Monoxide (CO)                | 1.29                 | 0               | 0.909                  |
| Total emissions(grams/mile)         | 10.58                | 0               | 9.085                  |
Figure 4: Emission graph for hybrid, electric, and conventional vehicles

Table 3: Calculation of overall efficiency for different driving cycles

| Type of Vehicle | Fuel Converter | Clutch | Torque Coupling | Energy Storage | Motor Controller | Gear Box | Final Drive | Wheel/Axle | Auxiliary Load | Aero | Rolling | Efficiency = Aero + rolling / fuel in-storage |
|-----------------|----------------|--------|-----------------|----------------|-----------------|----------|-------------|------------|----------------|------|----------|-----------------------------------------------|
| **Conventional Vehicle** |                 |        |                 |                |                 |          |             |            |                |      |          | 0.027                                          |
| In              | 128            | 1549   |                 | 1308           | 1225            | 1225     | 1132        | 0          |                |      |          |                                               |
| out             | 190            | 1308   |                 | 1225           | 1225            | 1132     | 0           |            |                |      |          |                                               |
| Loss            | 109            | 241    |                 | 83             | 0               | 93       | 762         | 66         | 289            |      |          |                                               |
| Efficiency      | 0.15           | 0.84   |                 | 0.94           | 1               | 0.92     | 0           |            |                |      |          |                                               |
| **Electric Vehicle** |               |        |                 |                |                 |          |             |            |                |      |          | 0.145                                          |
| In              | 111            | 1574   | 175             | 209            | 105             | 1755     | 1645        | 153        | 0              |      |          |                                               |
| out             | 157            | 1392   | 175             | 1739           | 373             | 1645     | 1645        | 0          |                |      |          |                                               |
| Loss            | 954            | 182    | 0               | 39             | 682             | 110      | 108         | 762         | 66             |      |          |                                               |
| Efficiency      | 0.14           | 0.88   | 1               | 0.88           | 0.35            | 0.94     | 1           | 0.93        | 0              |      |          | 0.036                                          |
| **Hybrid Vehicle** |               |        |                 |                |                 |          |             |            |                |      |          |                                               |
Three different kinds of vehicles, conventional, hybrid and electric vehicles are run on different driving cycles namely, Manhattan, urban dynamometer driving schedule and arterial. Step by step, energy in, energy out, losses and efficiency of each component is calculated and tabulated as shown in

| Driving cycle-ARTERIAL | Conventional Vehicle | Electric Vehicle | Hybrid Vehicle |
|------------------------|----------------------|-----------------|---------------|
| **In** | 6493 | 1391 | 1367 | 127 | 1271 | 204 |
| **out** | 1537 | 1367 | 1271 | 127 | 1180 | 0 |
| **Loss** | 4956 | 24 | 96 | 0 | 91 | 204 |
| **Efficiency** | 0.24 | 0.98 | 0.93 | 1 | 0.93 | 0 |
| **-** | | | **0.09** | | | |

| **In** | 299 | 1867 | 1541 | 142 | 2 | 1422 | 204 |
| **out** | 204 | 6 | 1541 | 1422 | 142 | 2 | 1323 | 0 |
| **Loss** | 120 | 326 | 119 | 0 | 99 | 204 |
| **Efficiency** | 0.8 | 0.83 | 0.92 | 1 | 0.93 | 0 |
| **-** | | | **0.34** | | | |

| **In** | 6104 | 1224 | 17 | 27 | 360 | 841 | 1727 | 161 | 5 | 1615 | 204 |
| **out** | 1224 | 1208 | 17 | 27 | 102 | 2 | 519 | 1615 | 161 | 5 | 1507 | 0 |
| **Loss** | 4880 | 16 | 0 | 74 | 322 | 112 | 0 | 108 | 204 |
| **Efficiency** | 0.2 | 0.98 | 1 | 0.83 | 0.62 | 0.93 | 1 | 0.93 | 0 |
| **-** | | | **0.1** | | | |

| Driving cycle-UDSS | Conventional Vehicle | Electric Vehicle | Hybrid Vehicle |
|---------------------|----------------------|-----------------|---------------|
| **In** | 22570 | 4219 | 4118 | 382 | 2 | 3822 | 958 |
| **out** | 4822 | 4118 | 3822 | 382 | 2 | 3534 | 0 |
| **Loss** | 17748 | 101 | 296 | 0 | 288 | 958 |
| **Efficiency** | 0.2 | 0.98 | 0.93 | 1 | 0.92 | 0 |
| **-** | | | **0.093** | | | |

| **In** | 440 | 5947 | 4643 | 427 | 6 | 4276 | 958 |
| **out** | 678 | 1 | 4643 | 427 | 6 | 3964 | 0 |
| **Loss** | 279 | 1304 | 368 | 0 | 311 | 958 |
| **Efficiency** | 0.85 | 0.78 | 0.92 | 1 | 0.93 | 0 |
| **-** | | | **0.34** | | | |

| **In** | 22212 | 4888 | 52 | 03 | 580 | 1610 | 5203 | 486 | 2 | 4862 | 958 |
| **out** | 4888 | 4799 | 52 | 03 | 243 | 9 | 604 | 4862 | 486 | 2 | 4521 | 0 |
| **Loss** | 17323 | 90 | 0 | 96 | 1006 | 341 | 0 | 341 | 958 |
| **Efficiency** | 0.22 | 0.98 | 1 | 0.87 | 0.38 | 0.93 | 1 | 0.93 | 0 |
| **-** | | | **0.103** | | | |
table 3. At the end, overall efficiency of all the types of vehicles considered in this paper is calculated for the different driving cycles.

5. RESULT AND CONCLUSION

The simulation results reveals that when electric, hybrid and conventional vehicles are compared for different driving cycles namely, manhattan, UDDS and arterial, the efficiency of electric vehicle for each of the above driving cycle is more as compared to other types of vehicles. The average efficiency of conventional vehicles is 0.070, hybrid vehicle is 0.079 whereas for electric vehicle it is much higher that is 0.275. When these vehicles are compared on basis of greenhouse emission it is found that the conventional vehicle emits 10.58 grams/mile, hybrid vehicle emits 9.085 grams/mile and electric vehicle emits zero grams/mile. So, economic and social status of any country can be raised by switching over to greener and cleaner solution i.e Electric vehicle.

6. References

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