

Analysis of On-Road Vehicle Propulsion Power Demand Due to Influence of External Factors

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Abstract—The escalating cost of fuel, increase in the pollution levels and its influence on human health are enforcing the Centre to think of alternative ways for road transportation. As a developing country, India is thinking about electric based road transportation. It is much vital to design and develop an electric based propulsion vehicles as per the customer / utilization requirement rather than having a generic design. Since the initial investment for such vehicle is huge, requirement specific design would reduce the initial cost as well as yields better performance during its operation with less running cost. This article holds the initial phase of the research work where the authors are trying to find out the influence of the external factors like road grading, road condition, loading capacity and aerodynamic shape of the vehicle on the motor rating with respect to utilization requirement. The mathematical results were presented with tangible conclusion.

I. INTRODUCTION

TRANSPORTATION is considered as livelihood of any country's economy. According to Indian Auto Industry, a total of 21.86 million units of domestic vehicles were sold within India during 2016 – 2017. Table 1 gives the category wise split up for the vehicle sale in India.

TABLE I
VEHICLE SALES IN INDIA DURING 2016 2017

Category	Units in Million
Passenger Vehicles	3.05
Commercial Vehicle	0.71
Two Wheelers	17.59
Three Wheelers	0.51

The total vehicle population in India has grown tremendously and figure 1 reflects the growth of vehicles in India between 1951 till 2015 (recent data officially available). Steep growth in the vehicle population could be found for two wheelers.

All these vehicles emit harmful gases for their operation. According to WHO global air pollution database (May 2nd 2018), 14 Indian cities are on the top 15 most polluted cities around the world in terms of PM 2.5 concentrations, with the worst being Kanpur. High pollution level leads to severe health implications like respiratory disease, such as asthma. This raising concern moves the Centre to promote electric vehicles for public transportation in cities with population above 10 lakh. With a strong target of moving towards

electric based transportation by 2030, the statement of Volvo planning to phase out internal combustion engine and produce only electric or hybrid vehicles by 2019 (livemint, 2 May 2018) adds concrete support for the Centre.

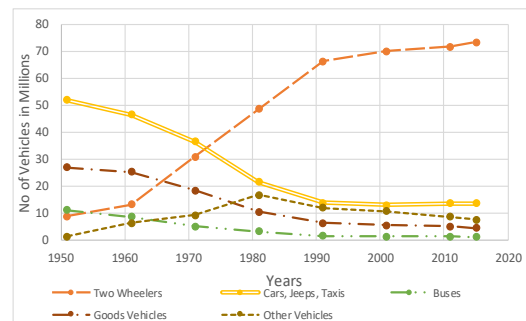


Fig. 1. Vehicle population growth in India (Source: MRTI, India).

The Centre is also moving towards 175GW renewable energy production by 2022 which will help in meeting the rise in energy demand. Out of 175 GW 100 GW is planned to be harvested from solar PV. This requires storing of electricity when available. Lead and Lithium Ion batteries are presently considered for storing electric energy. The price of Lithium Ion battery is 250 USD/kWhr as of 2017 which is 58% less when compared to the cost during 2011. This is expected to come around 100 USD/kWhr by 2024. All the prevailing scenarios aid kick start of electric vehicle programme. Electric vehicles are also seen as an alternative for energy storing systems.

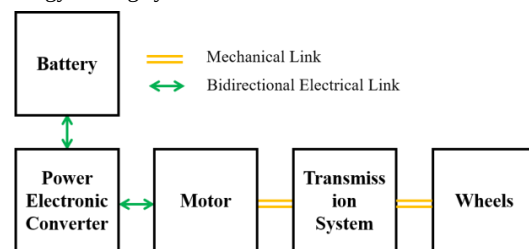


Fig. 2. Block Diagram of Electric Vehicle

Electric vehicle consists of a battery which acts as the onboard power source, a motor for converting the electric energy to the required mechanical energy for propulsion, transmission system for coupling the motor shaft to the wheels. The Power electronic converter does the speed

control of the motor as per the driver's torque demand. Among these, the motor and the battery holds larger share in the initial cost of the vehicle. The performance of the electric vehicle primarily depends on the proper selection of motors. The motor starting torque is much essential to move the vehicle from stand still condition and should be capable of delivering torque at different loading condition. As the efficiency of the motor is higher than that of internal combustion engine, electric propulsion system exhibits better running cost. Among various motors available the most commonly used motors are Brushless DC motor (BLDC), AC induction motor, DC Motor and Switch Reluctance Motor [1]. Though BLDC motor is expensive, it can offer high starting torque even at zero speed and provide maximum power even at 10000 rpm. This facilitates usage of single speed gear box system.

Since the objective of this research article is limited to analyze the impact of the motor power rating due to the external factors like

- Road grading which differentiates between hill or plains driving
- Road condition which affects the road tire friction
- Loading capacity which deals with load carrying capacity
- Aerodynamic shape of the vehicle which creates negative force on the vehicle movement

An elaborate analysis has been presented based on the above objectives in the following sections.

II. TRACTIVE FORCE COMPUTATION FOR VEHICLES

The tractive force generated by the propulsion system of the vehicle has to meet the force required to

- Propel the vehicle with the inertia
- Overcome road resistance offered by the condition of the road
- Overcome aerodynamic drag
- Overcome the resistance due to road gradient / slope.

This section of the article discusses about the various factors on which these forces depend upon [2], [3].

A. Inertial force

The inertial force depends upon the weight (M) to be carried as well as the acceleration requirement. Commercially, acceleration (acc) is well known as "time to reach maximum speed" or the "pick up time". The below equation gives the force F_m required to overcome inertia.

$$F_m = M * acc \quad (1)$$

The inertial force increases with the acceleration as well as the weight. The weight varies between the total curb weight of the vehicle + driver (minimum) and the maximum laden weight (vehicle + driver + maximum allowed load). This causes the acceleration to vary as F_m remains constant once after the vehicle is launched. The driver could feel the change in the vehicle behavior at different loading

conditions.

B. Road Resistance

The tire and road friction also adds negative force to the vehicle propulsion system. Equation (2) provides the relation between the force F_{frict} required to overcome road resistance and the road friction coefficient f_r .

$$F_{frict} = M * g * f_r \quad (2)$$

where g is the gravity due to acceleration. Road friction coefficient varies from 0.01 to 0.3. Lower value of f_r leads to better mileage since the resisting force is less. For a good concrete road, the value of f_r is 0.01 and for roads with dune, f_r is 0.3. Tire with deflated pressure offers more resistance and consumes more power from the onboard power sources reducing the millage.

C. Aerodynamic Drag

Aerodynamic drag or air friction offers a negative force for the movement of the vehicle. Driving vehicle with improper aerodynamic shape against the wind flow will also lead to power wastage. Equation (3) presents the relationship between the force created due to air friction and the aerodynamic shape.

$$F_{aero} = 0.5 * \rho_a * C_d * A_f * (V + V_w)^2 \quad (3)$$

where ρ_a is the density of air, C_d is the aerodynamic drag coefficient which varies between 0.15 to 1.5 for different vehicles having different frontal area A_f . The frontal area also varies between 0.557 and 1.67 sq. meters with respect to the selected C_d values.

D. Grading Resistance

Resistance offered to the movement of the vehicle due to slope or grading of the road. This grading can be computed by equation (4). More the grading, more the force is required for propulsion. This grading will be different in hills and plains.

$$F_{grad} = M * g * \sin(\theta) \quad (4)$$

The total tractive force F_{total} required to move the vehicle can be computed by adding the above four equations. If the radius of the wheel, w_r is known, then the torque required on the wheels, T can be found out as:

$$T_{wheels} = F_{total} * w_r \quad (5)$$

The power required from the propulsion system can be found by equation (6)

$$P_{req} = \frac{V}{\eta_t} (F_m + F_{frict} + F_{aero} + F_{grad}) \quad (6)$$

where η_t is the efficiency of the transmission system. For a direct drive propulsion system (wheels fixed to the motor shaft) the value is considered to be 1.

III. PARAMETERS FOR ANALYSIS

In the above section, the force required to overcome vehicle inertia depends on the acceleration time selected and the weight. The acceleration performance varies under different loading conditions. The road friction coefficient f_r ,

differentiates the vehicle as on road or off road. This makes the vehicle even more application specific. More power is required in case of off road vehicles. This restricts the usage of vehicles to a particular application. In order to reduce the resistance offered by the aerodynamic shape, proper designing is required. The air density also adds to this resisting force. The density varies with temperature. These parameters influence the total power requirement for propulsion. Hence this research article considers the parameters presented in Table II to study about their influence on the selection of motor for a passenger electric vehicle (car) as well as a commercial truck applications [4]-[6].

TABLE II
PARAMETERS CONSIDERED FOR ANALYSIS

Parameters	Values
Mass, M	1060, 1400, 3200, 7200 kg
Maximum Speed, V	100 km/hr
Acceleration Time, t	5, 10 secs
Road Slope, θ	0, 3, 5, 10 degrees
Road Friction Coefficient, f_r	0.1
Aerodynamic Drag, C_d	0.15, 1.5
Frontal Area, A_f	0.557, 1.67 m ²

For detailed analysis, coding is performed in MATLAB with GUI interface to plot the motor characteristics (Figure. 3).

The above parameters have been classified according to various vehicle driving scenarios and application, categorized and presented in Table III. Total of 8 scenarios have been obtained for which the weight of the vehicle is varied between minimum and maximum laden weight in that segment.

TABLE III
PARAMETERS CLASSIFIED ACCORDING TO APPLICATION

Scenarios	Vehicle Type	Time to reach Max Speed t in sec	Road Slope θ in degrees
1	On-road ($f_r=0.1$) Passenger Car ($A_f=0.557$, $C_d=0.15$)	5	0, 3 and 5
2	On-road ($f_r=0.1$) Passenger Car ($A_f=0.557$, $C_d=0.15$)	10	0, 3 and 5
3	On-road ($f_r=0.1$) Passenger Car ($A_f=0.557$, $C_d=0.15$)	5	10
4	On-road ($f_r=0.1$) Passenger Car ($A_f=0.557$, $C_d=0.15$)	10	10
5	On-road ($f_r=0.1$) truck ($A_f=1.67$, $C_d=1.5$)	5	0, 3 and 5
6	On-road ($f_r=0.1$) truck ($A_f=1.67$, $C_d=1.5$)	10	0, 3 and 5
7	On-road ($f_r=0.1$) truck ($A_f=1.67$, $C_d=1.5$)	5	10
8	On-road ($f_r=0.1$) truck ($A_f=1.67$, $C_d=1.5$)	10	10

IV. RESULTS AND DISCUSSION

Based on the above specifications considered for different scenarios, a total of 65 simulations have been carried out to

study about the influence of the parameters discussed in section I on the motor specification is carried out. A 200-volt DC motor of 3000 rpm is considered to be the propulsion system powered from a 200v DC bus system with 200 AH battery backup [7]. For $M=1500$ kg, $t=5$ secs, $\theta=0$, $f_r=0.1$, $C_d=0.15$, $A_f=0.557$, the power required is 252.35 kW and the charge in the battery shall lost for 0.101 hrs.

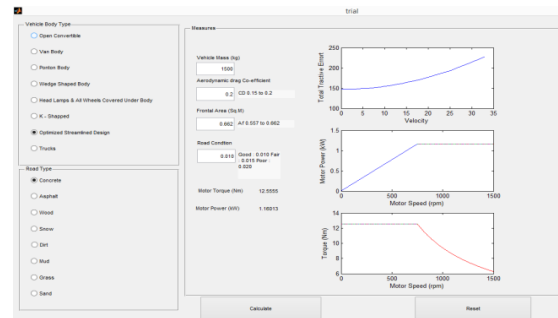


Fig. 3. MATLAB GUI for plotting motor characteristics.

The results have been categorized according to the various applications as per the parameter ranges selected and are presented in figures 4 to 9.

From figures 4 and 5, the maximum power demand for the climbing a grade of 5 degrees reduces by 34 % when the acceleration time is increased from 5 to 10 seconds. This would considerably extend the distance covered with the same battery rating as well as the cost of the motor. The percentage remains the same for the vehicle running on a hilly region with a grading of 10 degrees (fig. 6). The power demand for the onroad vehicle running on hills is 38 % more than that of the vehicle running on plains with a maximum grading of 5 degrees.

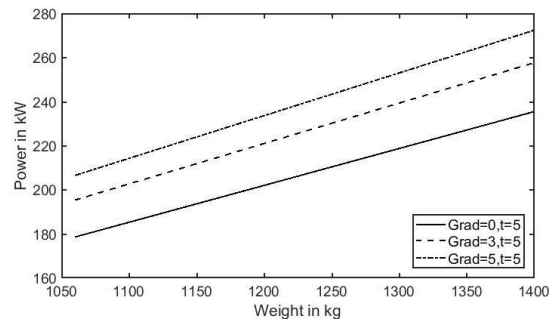


Fig. 4. On-road passenger vehicle with low grading and fast acceleration ($t=5$ sec)

For an increase in weight by 24 %, the power demand also increases by 25 % for all values of road grading considered as well as for the acceleration time.

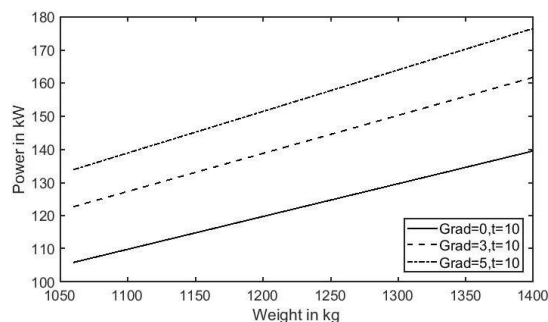


Fig. 5. On-road passenger vehicle with low grading and slow acceleration ($t=10\text{sec}$)

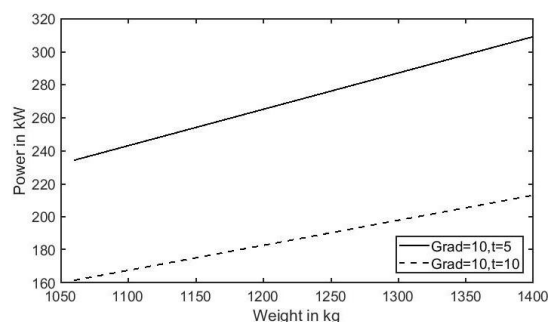


Fig. 6. On-road passenger vehicle with high grading

For the maximum grading the percentage increase of power remains at 23 % for both the accelerations selected at minimum and maximum loads.

The parameter variation corresponding truck for various external factors have been presented from figure 7 to 9. Increase in acceleration time by 5 seconds reduced the power demand by 34 % for the vehicle running on plains with a maximum of 5 degree grading.

The power demand for the on road truck running on hills is 40 % more than that of the vehicle running on plains with a maximum grading of 5 degrees.

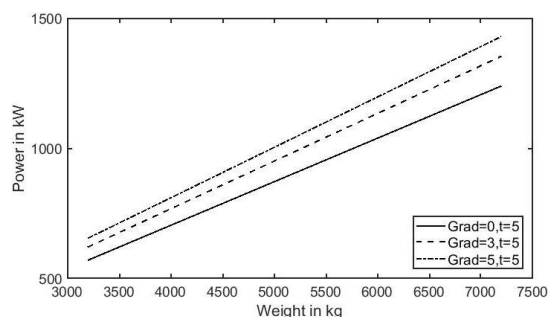


Fig. 7. On-road truck with low grading and fast acceleration ($t=5\text{sec}$)

The linearity has been absorbed for the truck for different road grading at minimum and maximum loads. 5 to 10 percentage deviation witnessed at the load extremes. As the load was increased by 55 % the power demand also increased by 55%.

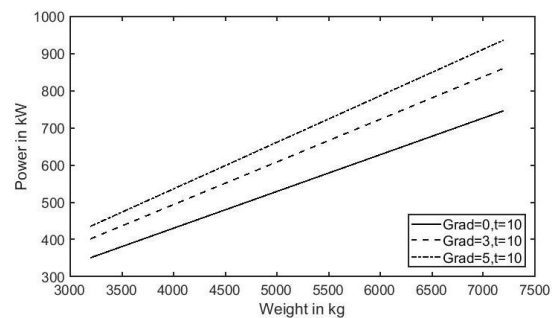


Fig. 8. On-road truck with low grading and slow acceleration ($t=10\text{sec}$)

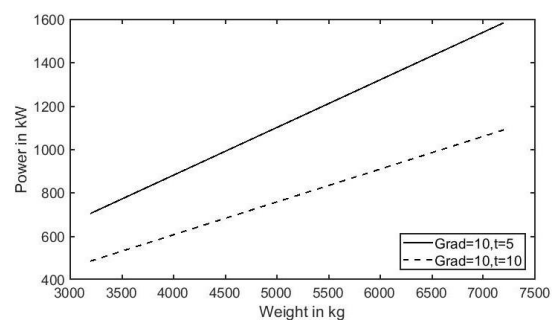


Fig. 9. On-road truck with high grading

Inference 1: Proportionate increase of Power demand absorbed for all the category when the load is increased (23 to 24 %).

Inference 2: Difference in demand for both plain and hill applications, passenger vehicle and truck had same proportion (38 to 40 %)

Hence designing of electric vehicle with the knowledge about the application for which it is to be utilized, would result in better customer affordability and higher performance.

V. CONCLUSION

The external factors of a vehicle like aerodynamic drag, road friction, mass of the vehicle as well as the vehicle performance metric: the acceleration time, are considered to find out how they influence the selection of the motor for electric vehicle application. Increase in acceleration time almost reduced the power demand by 34%. The power demand increased by same percentage as that of the increase in weight of the vehicle. Hence it is required to design a vehicle which optimally suits the working environment.

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