A Methodology for Selection of Optimum Power Rating of Propulsion Motor of Three Wheeled Electric Vehicle on Indian Drive Cycle (IDC)

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Abstract – **Optimum power rating of propulsion motor is an important issue for designing efficient drive train for a three wheeled battery operated electric vehicle application on standard drive cycle like Indian Drive Cycle of Indian urban and suburban areas. This paper deals with proper estimation of power rating of electric motor by root means square technique while considering the limitations of overloading and under loading operation of motor used in electric vehicle along with some specified design parameters, aiming towards better performance than that of a conventional IC engine driven vehicle. Dynamics of three wheeled vehicle is simulated on MATLAB/Simulink environment under a sequence of road grade angle variation in Indian Drive cycle (IDC), which is formulated by Automotive Research Association of India, Pune. Using simulated vehicle dynamics, power rating of the motor is estimated so that it can be operated efficiently and safely throughout the entire Indian drive Cycle.**

Keywords – Indian drive cycle (IDC), Tractive Force, Tractive power.

I. INTRODUCTION

India’s roads are becoming more congested each year with IC engine driven three wheelers, which are worsening India’s already prevalent pollution problem. With the factors of pollution and increased traffic in mind, the best way to revamp the situation, is to develop an efficient Battery Operated Three Wheeled vehicle, which can be achieved with proper selection of Power rating of Propulsion Motor. The shortcomings, which caused the EV to lose its early competitive edge, have not yet been totally overcome. Indeed, EVs have a low energy density and long charging time for the present batteries. Therefore, optimal energy management is very important in EVs; in addition optimum design of the electric motor, selection of a proper drive [1], and optimal control Strategies [2] are the other major factors in EVs. Many researchers [3], [4], [5] had performed vehicle dynamics simulation for selection of motor power. Moreover, they only considered average tractive power demand at zero degree slope and they did not consider its tractive torque and tractive power demand at different grade angles. As a result propulsion motor cannot provide sufficient tractive torque at higher grade angles. To overcome these issues, authors have considered short time tractive power demand of motor at its rated, under rated and over rated operation and adopted root means square technique to find optimal rating of motor

This paper is organized in six sections. Section II provides detailed analysis of Indian drive cycle. Section III represents the formulation of vehicle dynamics for three wheeled electric vehicle. The vehicle dynamics is modelled in MATLAB/Simulink platform considering some specified design parameters of the vehicle and simulation results following Indian drive cycle are presented in Section IV. By analysing the results with suitable methodology suggested in section V, power rating of electric motor is selected which gives optimal performance in terms of over loading and under loading capacity of motor followed by conclusion in section VI.

II. INDIAN DRIVE CYCLE

Drive cycle is a sequence of measured data points under several vehicle operating conditions (idle, acceleration, cruise, deceleration, braking and gear changing), which is a representative plot of the driving behaviour in a given city or region. Drive cycles [6] are used in propulsion system simulations designed specifically to model the drive system only and predict performance of electric motor, transmissions, electric drive systems, batteries [7], [8], [9], [10], [11]. The first driving cycle in India was developed in early 80's to quantify fuel consumption based on a fuel study in Delhi. Later in 1985, Automotive Research Association of India (ARAI) collected extensive data in major cities to develop a standardized driving cycle .This driving cycle is known as the Indian driving cycle (IDC) shown in the figure below.

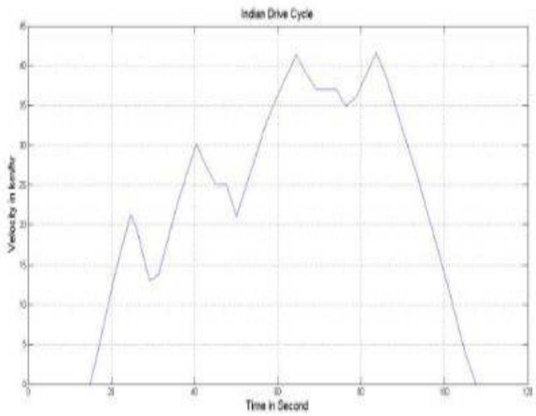

Fig. 1: Indian Drive Cycle Velocity (km/hr) vs Time (second) diagram

The details of the IDC are listed in a Table1:

Maximum speed (km/hr)	42
Average speed (km/hr)	21.93
Maximum Acceleration (m/sec^ 2)	0.66
Maximum deceleration (m/sec^ 2)	-0.63
Idling	14.81 % of Total time (108 sec)
Steady speed periods	12.04 % of Total time(108 sec)
Acceleration	34.89 % of Total time(108 sec)
Deceleration	34.26 % of Total time(108 sec)
Distance Travelled (km)	0.658

Table I - Details information of IDC

III. Formulation of Vehicle Dynamics Introduction to Indian Drive Cycle

Vehicle operation fundamentals mathematically describe vehicle behavior based on the general principles of mechanics. A vehicle is a complex system which consists of thousands of components. Since this paper is related to electric vehicle power trains, vehicle dynamics as shown in figure 2, is restricted to one-dimensional movement. The force, propelling the vehicle forward and transmitted to the ground through the wheels, is known as Tractive Force which mainly consists of four components:

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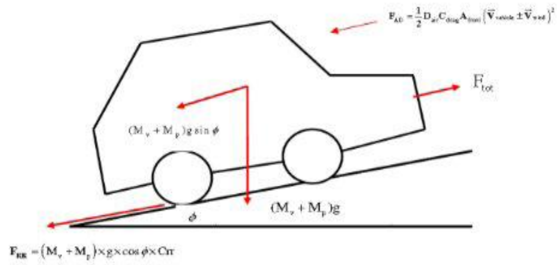

Fig. 2: Different forces acting on vehicle

Rolling Resistance Force (F_{RR})

The force due to rolling resistance [12] is a function of many factors such as tyre design, inflation pressure, vehicle weight and speed. Given a tyre design and a standard inflation pressure, a rolling resistance coefficient (C_{rr}) can be found. C_{rr} is dimensionless quantity that describes resistance to forward motion per unit vehicle weight. Rolling resistance force then becomes a function of C_{rr} and vehicle weight. The expression for FRR is given in equation 1:

$$\mathbf{F_{RR}} = \left(M_v + M_p\right) \times g \times \cos\phi \times Crr \tag{1}$$

Aerodynamic Drag Force (F_{AD})

Aerodynamic drag [12] is created by the displacement of air as the vehicle moves, the friction of the moving air with the vehicle surface and turbulence in the wake of the vehicle. The force due to aerodynamic drag depends mainly on the shape of the vehicle, the density of the surrounding air, and the relative velocity of the vehicle and wind. The expression for force due to aerodynamic drag FAD in still air is given in equation 2:

$$F_{AD} = \frac{1}{2} D_{air} C_{drag} A_{front} \left(\vec{V}_{vehicle} \pm \vec{V}_{wind} \right)^2 \qquad (2)$$

Inertia Force (F_I *)*

The force due to inertia [12], [13] stems from changes in velocity (acceleration and deceleration). Unlike F_{AD} and F_{AR}, F_I can be positive or negative. FI is positive (in opposition to vehicle movement) when accelerating, and negative (contributing to vehicle movement) when decelerating. Many models approximate rotational inertia by using a rotational inertia compensation factor (r_i) to increase the vehicle's apparent mass in the F_I term by 3% to 4%. Fortunately the effect is relatively small: the increase in inertia brought about by r_i =1.04 (4%) would result in the same increase in power demand that would result from a 4% increase in vehicle weight. The expression for inertia force due to forward acceleration and rotational inertia becomes

$$F_I = \left(M_v \times r_i + M_p \right) \times a \qquad (3)$$

Where, a $\frac{dV}{dt}$ = acceleration (or deceleration) rate

Force due to Grading:

As a vehicle ascends a grade, the force of gravity imposes an additional energy demand equal to the potential energy being invested in the vehicle due to the change in elevation. The grade of a hill is typically described in terms of its inclination from the horizontal in degrees or radians, referred to as φ. The force of gravity is determined by the mass of the vehicle and the gravitational constant. The component of downward force that acts in the direction of φ is

$$F_s = \left(M_V + M_p \right) \times g \times \sin\phi \qquad (4)$$

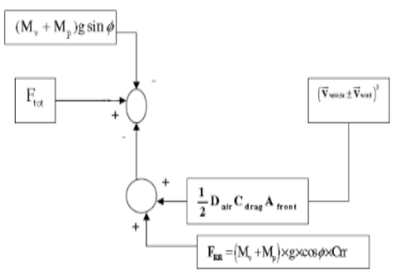

Fig. 3: Block diagram representation of different force acting on vehicle

Tractive torque and power:

Total tractive torque required at the wheel to overcome the road load is given by

$$T_{tot} = \int_0^T \left(F_{RR} + F_{AD} + FI \right) R_w \, dt \qquad (5)$$

Power is energy per unit time. Since energy is force multiplied by distance, and velocity is distance per unit time, it can be shown that power is force multiplied by velocity.

$$P_{tot} = \int_0^T \left(F_{RR} + F_{AD} + FI \right) V_{vehicle} \, dt \qquad (6)$$

Here the condition that has been given that if F_{tot} is less than or equal to zero and F_I is less than zero, Then P_{tot}=0, this situation generally happens for deceleration of the vehicle by applying brake.

Transmission

From wheel to the motor shaft there will be differential gear by which speed of the two wheels can be varied simultaneously. When the vehicle is moving in a straight line then the speed of two wheels are same but when it takes a turn then the inner will rotate at slow speed rather than outer wheel which rotate at comparatively high speed. Then there will be transmission losses in differential. So considering all, power required at the motor shaft to propel the vehicle at a particular instant is

$$M_{power} \quad \frac{P_{tot}}{\eta_t} \qquad (7)$$

V. CALCULATION OF TOTAL POWER REQUIRMENT & RESULTS

For calculation we have taken some of the parameters such:

SL NO	Parameter	Value
1	Mass of the vehicle	400 kg
2	Weight of the passenger	400 kg
3	Radius of the vehicle wheel	0.2365 meter
4	Rotational inertia factor	1.02
5	Gravitational acceleration	9.81 m/s^2
6	Rolling resistance coefficient	0.0183
7	Grade angle of road	0 to 15 degree
8	Density of air	1. 2 kg/m^3
9	Drag coefficient	0.034
10	Frontal area of the vehicle	2.223 m^2
11	Wind velocity component	2 m/s
12	Efficiency of the drive train (Transmission gear & differential)	0.90
13	Motor and controller efficiency	0.85

To estimate the total power and energy requirement for driving on Indian Drive Cycle, some of the assumption is mentioned like during deceleration of the vehicle, motor will be disconnected from the power supply. For calculating energy requirement we have taken our drive cycle for 120 sec. For this duration average speed is coming 21.93 km/ hour and vehicle is travelling 0.658 km at zero degree slopes. As the vehicle has to move around 100 km in a single charge so it need almost 4.55 hours time ie, 16415 sec. For achieving this drive cycle is repeated almost 151 times in simulation. In calculation authors have kept rolling resistance coefficient, air drag coefficient, payload of the vehicle, wind velocity (opposing vehicle speed) as constant. Authors have only varied grade angle of the road.

Simulation Results at Zero degree slope :

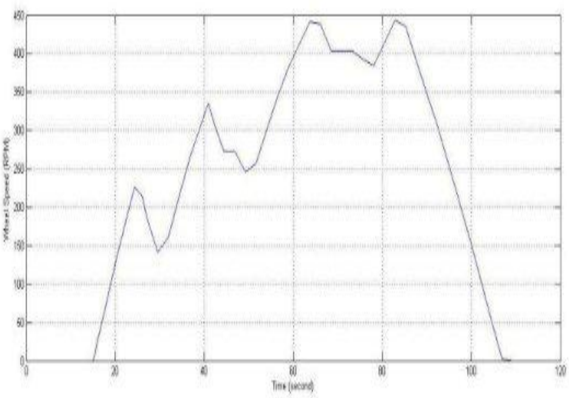

Fig. 4: Wheel speed(rpm) vs time (sec) plot

This is the plot of wheel angular speed (RPM) vs time (Second) on IDC. Motor shaft angular speed can be calculated with fixed gear ratio but it can be varied as per as the requirement at different speed of the vehicle through different stages gear changing arrangement.

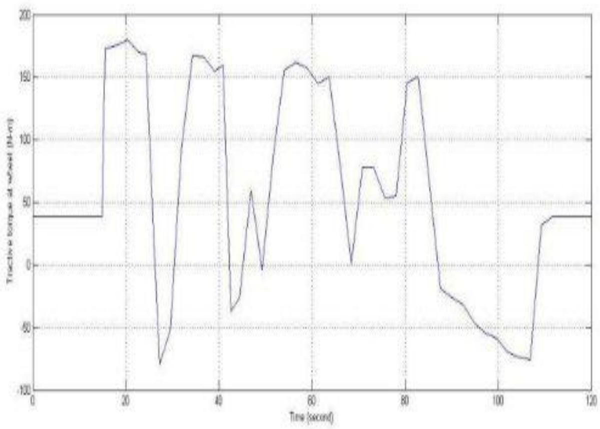

Fig. 5: Tractive torque (N-m) vs time (sec) plot

Figure 5 shows the tractive torque required at the wheel (N-m) at different instant of time (sec). As two rear wheels are symmetrical, so for a single motor configuration, it will be equally divided to the individual wheel. Here also authors have can use fixed gear ratio for reducing the load torque demand at the motor shaft. But it can be varied as per as our requirement at different speed of the vehicle through different stage gear changing arrangement because during high speed, torque will be less and vice versa.

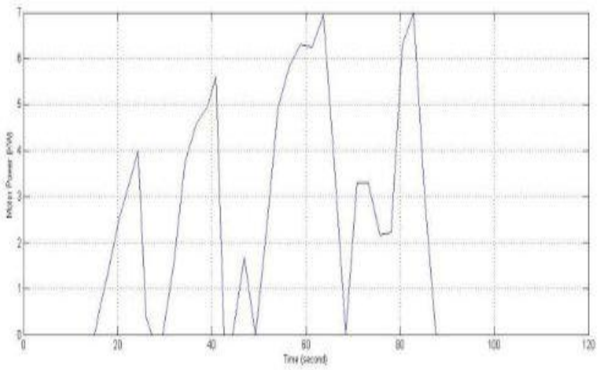

Fig. 6: Motor power (kW) vs time(sec) plot

Figure 6 represents the operation of the motor at different power rating (kW) at different speed of the drive cycle with acceleration and deceleration. It is found that for maximum velocity and maximum acceleration rate of the drive cycle motor will be operated at 7 kW. During deceleration motor will be disconnected from the power supply and we will apply regenerative braking concept to feed the energy to the battery.

VI. Methodology For Optimum Power Rating Selection Of Motor

Different researchers are often specified to have more/less power (kW) than it is actually required. These under loaded motors cost more to run than properly loaded ones because they operate on a less efficient part of their load curve. At the other extreme, some motors are called upon to deliver more power than they are designed to deliver. They will do this for a while, but they overheat and eventually fail. In drive cycle, frequent acceleration and deceleration demand sudden increment or decrement of power requirement than rated, so choice of base power requirement for driving on Indian roads is really challenging. From the plots, it is very much clear that motor power requirement at different instant of time on IDC is different. So for selecting motor power rating, it will not be accurate to adopt simple averaging technique. Here authors have adopted Root Mean square technique, which is basically weighted average technique.

The RMS Power of the motor can be calculated by equation 8

$$M_{RMS} = \sqrt{\left(\sum (M_{power}{}^{2} \times t)/T\right)} \quad (8)$$

Where t is the instantaneous time in second at which M_{power} is calculated and T is the total run time in second.

The RMS Torque of the motor can be calculated by

$$T_{RMS} = \sqrt{\left(\sum (T_t^{2} \times t)/T\right)} \quad (9)$$

Where t is the instantaneous time in second at which T_t is calculated and T is the total run time in second.

It is found that for maximum velocity and maximum acceleration rate of the drive cycle motor will be operated at 7 kW. Motor RMS Power coming out from our calculation is 3.5kW. We can overrate a motor almost 2 times for few second. So we have chosen 3.5 kilo-Watt motor to meet the power requirement at high acceleration rate and high speed.

Motor Power Requirement for the vehicle moving with acceleration and constant speed at different grade angles are tabulated in table 2:

Road Grade Angle(degree)	Maximum Constant Vehicle Speed (km/hr)	Motor RMS Power (kW)	Maximum Vehicle Speed (Km/Hr) with acceleration following IDC	Short time Peak Motor Power (kW)
0	38	3.5	42	7
1	30	3.5	35	7
2	23	3.5	30	7
3	19	3.5	25	7
4	16	3.5	20	7
5	13	3.5	15	7
7	10	3.5	13	7
10	8	3.5	10	7
15	5	3.5	5	7

Table 2: Requirement of motor power for moving with acceleration and constant limited speed in different grade angle

In this Table 2, we have shown different speed of the vehicle, one can achieve without violating its rated and overloading capacity. According to that we have put the limit in the vehicle velocity at different slope angle as shown in the Table 2.

VII. CONCLUSION

In this paper we have simulated vehicle dynamics considering different kind of forces acting on the moving vehicle at different road grading conditions by accepting Indian Drive cycle pattern and from simulation results we have calculated the requirement of tractive force, torque, power for the vehicle propulsion system to drive the vehicle following particular drive cycle. From these simulation results, suitable power rating of the motor is estimated so that motor can be operated safely in efficient zone of its entire zone of operation. Finally authors conclude that considering specified parameters of the vehicle following Indian Drive Cycle, 3.5 kW motor will be sufficient for this particular application.

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NOMENCLATURE

M_v = Mass of the vehicle in Kg

M_p = Mass of payload in Kg

R_w = Radius of wheel in meter

r_i = Rotational inertia compensation factor (Dimensionless)

g = 9.81 m/s2 (gravitational constant)

C_{rr} = Rolling resistance coefficient (dimensionless)

φ = Road grade angle of the road in degree

D_{air} = Density of air (kg/m^3)

C_{drag} = Drag coefficient (dimensionless)

A_{front} = Projected frontal area (m^2)

$V_{vehicle}$ = Vehicle Speed (m/s)

V_{wind} = Wind velocity component (m/s)

η_t = Transmission efficiency

η_c = Motor and Controller efficiency

F_{tot} = Total Tractive (Resultant) force in (N)

F_{RR} = Force due to tire rolling resistance in (N)

F_{AD} = Force due to aerodynamic drag in (N)

F_I = Force to overcome inertia (acceleration, deceleration, traversing a grade) in (N)

P_{tot} = Tractive Power in Watt

T_{tot} = Tractive Torque in N-m

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