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Theoretical Calculation of Electric Vehicle Performance

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Abstract:- Electric vehicle is gaining popularity due to increasing concern for environment and green house emission with conventional fossil fuel vehicle. Electric vehicle may take time to become main stream in India, but demand and push from government is making it fast.

Electric vehicle typically use about one third energy as compared to gasoline powered vehicle because of high efficiency. Electrical motors convert over 85% of electric energy into mechanical power compared to less than 40% in internal combustion engine. Theoretical calculation of vehicle performance is key for sizing the gear ratios, battery and systems capacity to achieve desired performance.

Keywords:-
EV- Electrical Vehicle
SOC_e- Battery state of charge energy
DRR- Tire dynamic rolling radius
η – Transmission mechanical efficiency
g = acceleration due to gravity

I. INTRODUCTION

It is very important to match the capacity of motor, battery and system capacity for required performance. Electric vehicle key performance parameters involve vehicle max speed, acceleration and power consumption and range.

Typically for electric vehicle single gear ratio is used unlike in multi-speed transmission in conventional vehicles since motor deliver highest torque at low speeds and can achieve much higher speeds than conventional engines.

With higher ambient temperature and driving conditions in India there are safety, durability and performance changes for Li-ion battery. This challenges gives opportunity for innovative battery pack design and thermal management solutions.

II. EV Vehicle performance

Vehicle dynamics equation involves driving force and power loses. Important force term involve Vehicle Acceleration force, Drive Force from Motor, Rolling Resistance and Aerodynamic Resistance.

Acceleration force = Vehicle driving force - Rolling resistance - Aerodynamic resistance

Vehicle driving force can be calculated from motor torque (*T*), gear ratio, Transmission mechanical efficiency and dynamic rolling radius of tire (DRR)

Vehicle driving force = T x GR x η / DRR

Rolling resistance (*F*) is a function of tire load, inflation pressure and speed. Rolling resistance force can be calculated from rolling resistance coefficient and vehicle weight.

Rolling resistance = m x g x cos θ x μ

m = vehicle mass
θ = road gradient
μ = rolling resistance coefficient

Aerodynamic resistance is calculated from coefficient of drag, frontal area of vehicle and vehicle speed. Aerodynamic resistance is proportional to frontal area and square of vehicle speed.

Aerodynamic resistance = ½ x ρ x C_d x V^2 x A

ρ = air density
C_d = aerodynamic resistance coefficient
V = vehicle velocity
A = frontal area of vehicle

Rolling resistance and aerodynamic resistance can be measured with IS 14785 Coast down Test Method [1]. In coast down test vehicle deceleration time is measured to calculate the resistance force. Resistance force calculated is curve fitted to standard resistance function to calculate A and B.

$F = A + B \times V^2$

F = Resistance force
A= Rolling resistance
B = Aerodynamic coefficient

Correction coefficient of the rotating mass is calculated by equating total energy to translational and rotational energy.

$$\frac{1}{2} \times m_e \times v^2 = \frac{1}{2} \times m \times v^2 + \frac{1}{2} \times I_r \times \omega^2$$
$$m_e/m = 1 + I_r \times \omega^2 / (m \times v^2)$$
$$\delta = 1 + (I_w + I_m \times GR^2 \times \eta) / (m \times DRR^2)$$

m_e = equivalent mass
m = vehicle mass
I_r = moment of inertia of rotating parts
I_w = wheel moment of inertia
I_m = moment of inertia of motor rotating parts
GR = Gear ratio

Below is typical motor efficiency curve at different operating rpm's.

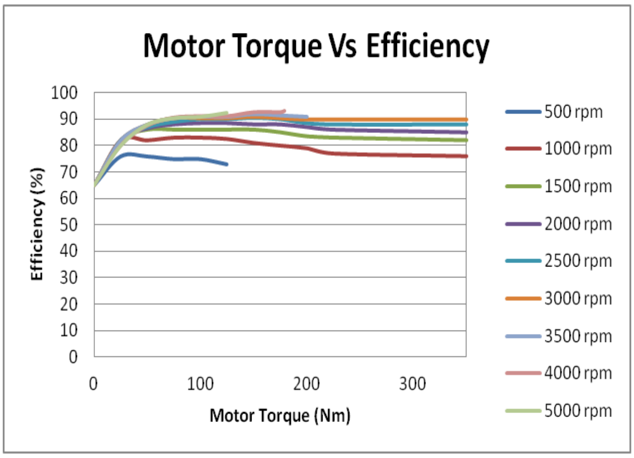

Figure 1. Chart Motor Torque Vs efficiency

There is power drop in battery due to electrode and ionic internal resistance. Higher battery discharge rate lead to higher battery power loss.

Battery Power loss = I^2 x r

I = Battery discharge current
r = Battery internal resistance

There is energy loss in battery power supplied to motor in inverter and motor.

Electric Motor Power = η_{pc} x η_m x P_d

η_{pc} = Power converter efficiency
η_m = Motor efficiency
P_d = Driving motor power supplied from battery

Below is typical power flow diagram for an electric vehicle. Battery cells are connected in series and parallel to get required voltage and rated charge capacity for required range. Battery capacity is effectuated by multiple factors like temperature and discharge rate. Battery performance drop considerably with temperature. Typical battery capacity range from 15 to 100Kwh.

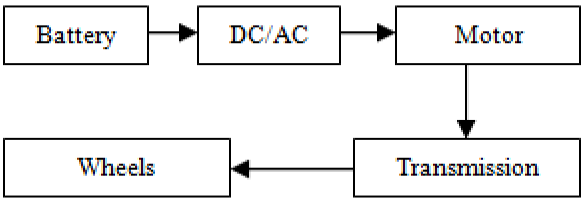

Figure 2. Electric vehicle energy flow

Battery state of charge energy (SOC_e) indicates percept of total capacity available at the moment. Open circuit voltage (OCV) is simplest method for estimation of SOC but since for Li-ion battery SOC Vs OCV is a flat curve other method like coulomb counting is used for SOC_e estimation.

SOC_e(i) = SOC_e (i-1) – Power consumption at instant(i) / C

SOC_e (i) = SOC_e at instant (i)
SOC_e (i-1) = SOC at instant (i-1)
C = Battery Capacity (kWh)

Li-ion cells are not operated below 20 to 30% SOC_e for better life. Below the limit battery management circuit will cut off the battery discharge hence there is always an unused battery capacity. Battery management system ensures the depth of discharge limit.

➢ *Calculation of road speed*

Vehicle road speed is calculated from motor rpm, gear ratio and transmission mechanical efficiency.

Tire rpm = Motor Rpm x Transmission efficiency/ Gear Ratio

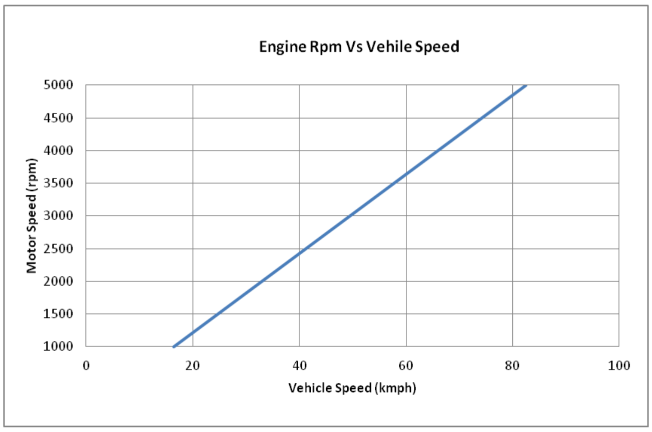

Figure 3. Chart Motor speed Vs vehicle speed

➢ *Max traction available at wheels*

Max wheel traction can be calculated form motor max power curve. Below is typical motor max power curve.

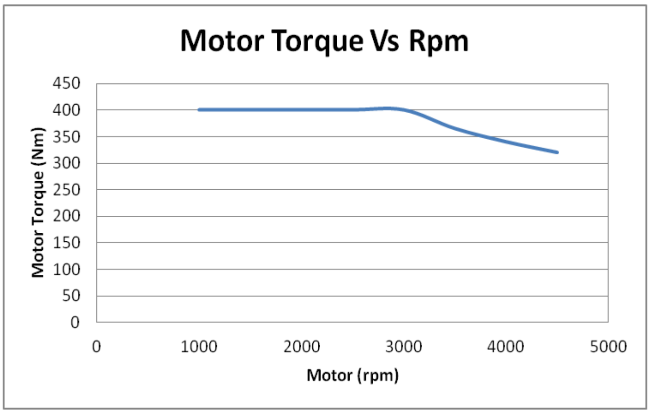

Figure 4. Chart Motor Torque Vs Motor speed

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Tire Traction Force = Motor Torque x Transmission efficiency x Gear Ratio/DRR

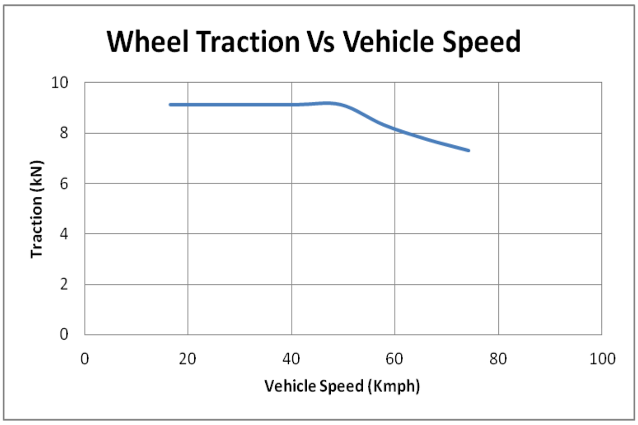

Figure 5. Chart Wheel Traction Vs Vehicle Speed

➢ *Vehicle Acceleration*

Vehicle acceleration can be calculated from acceleration force. Acceleration force is driving force from motor minus rolling and aerodynamic resistance

Acceleration force = Vehicle driving force - Rolling resistance - Aerodynamic resistance

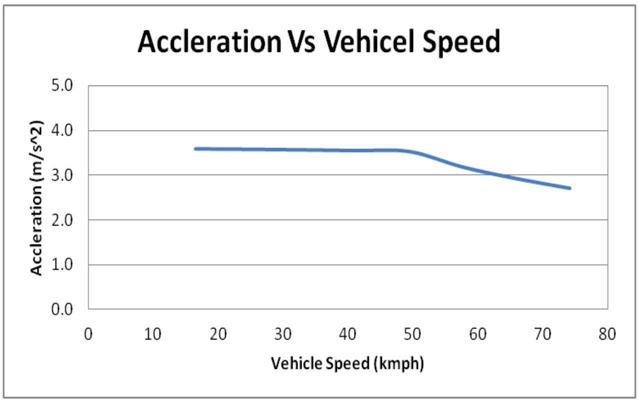

Figure 6. Chart Vehicle Acceleration Vs Vehicle Speed

➢ *Vehicle gradeability*

Vehicle gradeabilty can be calculated form force equation. When driving vehicle uphill on a gradient the vehicle dynamics equation will additionally have the grade resistance. The rolling resistance is also affected.

T x GR x η / DRR = m x g x cos θ x μ + Aerodynamic resistance + Grade resistance

Grade resistance = m x g x sin θ

Below chart show variation of gradeability Vs Max motor torque.

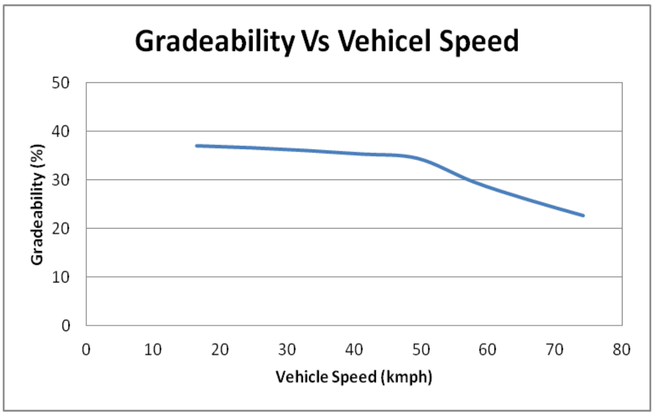

Figure 7. Chart Vehicle Gradeability Vs Vehicle Speed

Vehicle gradeabilty Vs vehicle speed can be calculated by below equation.

Grade resistance x velocity = Power available at wheel

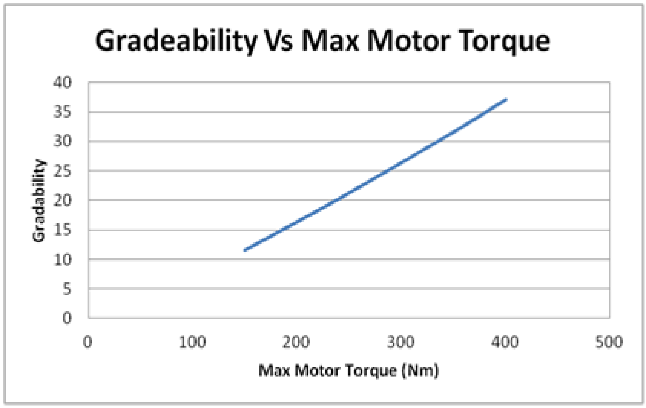

Figure 8. Chart Vehicle Gradeability Vs Max Motor Torque

➢ *Vehicle power consumption*

Vehicle power consumption involves power lost in rolling resistance, aerodynamic resistance and system efficiency. Typically vehicle power consumption is evaluated over standard cycles like NEDC cycle.

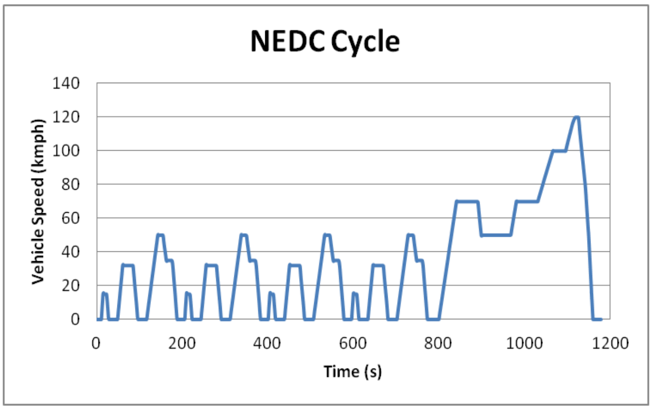

Figure 9. Chart Vehicle Speed Vs Time in NEDC Cycle

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Below is calculated instantaneous power consumption considering the resistance and component efficiency.

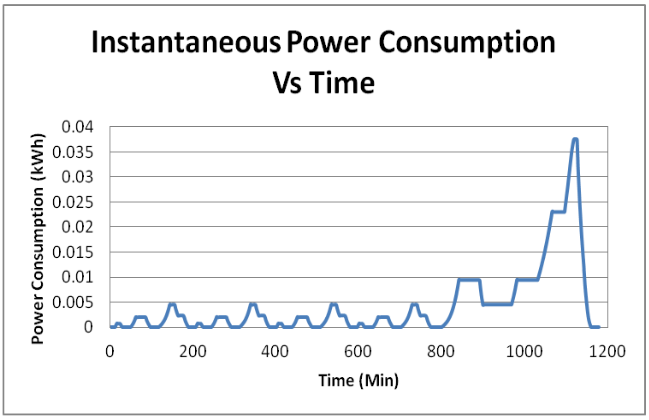

Figure 10. Instantaneous Power Consumption Vs Time

Below is calculated cumulative power consumption considering the resistance and component efficiency.

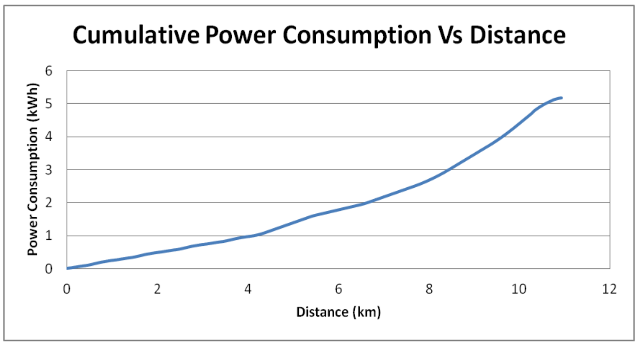

Figure 11.Cumulative Power Consumption Vs Distance

➢ *Battery SOC_e*

The SOC_e represent available battery energy remaining divided by rated energy capacity expressed in percentage.

SOC_e = Current available battery energy / Rated energy capacity x 100

Below is the SOC_e variation in NEDC cycle considering battery rated capacity of 100 kWh.

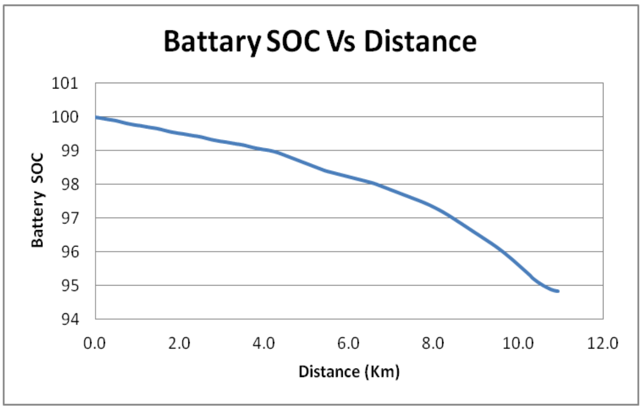

Figure 12. Battery SOC_e Vs Distance

➢ *Vehicle Range*

Vehicle range is directly proportional to battery charge capacity.

NEDC Range = Battery capacity / Power consumption in NEDC x NEDC Distance

With above extrapolation formula with battery capacity 100KWh expected range in NEDC cycle is 211km.Below chart represent variation of range with battery capacity.

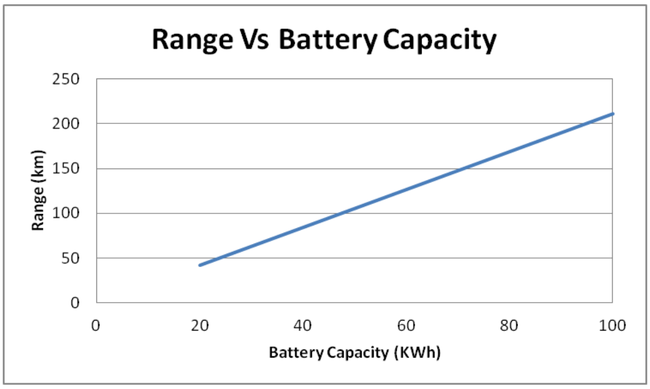

Figure 13. Vehicle Range Vs Battery Capacity

III. SUMMARY/CONCLUSIONS

Electric vehicle performance calculation is done to check adequacy of the motor and battery capacity requirement.

REFERENCES

[1]. IS 14785: Automotive Vehicles – Determination of Road-load Constants by Coast down Test Method.
[2]. ARAI CMVR TAP Document- Part 11 Chapter 4
[3]. AIS-040 – Electric Power Train Vehicle Method of Measuring the Range
[4]. MoRTH/TAP/CMVR-115/116
[5]. AIS-003 Automotive Vehicles – Starting Gradeability
[6]. AIS-048 Battery Operated Vehicle – Safety requirements of Traction Batteries