Calculation and Profiling of Energy Consumption Rate of an Electric Vehicle

Geetha, SubhomoyGanguly, Dipanjan Paul, ShubhamSahu, Shreyas Mehta,ShashankTiwari

Abstract: ***Electric vehicle (EV) energy consumption is different and dependent on number of external factors such as road topology, city driving, highway driving, driving style, ambient temperature etc. Improving battery performance is one of the most important factors in promoting the EV market by prolonging battery life reducing the cost of ownership and giving confidence in the product to potential customer. This paper consider a method of improving battery performance and its characteristics on different load in different vehicles and thus increase holding capacity. This will be realized by finding energy consumption rate(ECR), voltage of battery at different stage of vehicles.The goal of this paper is to detect its power consumption on different vehicle speed, torque, voltage output of the battery. All the testing has been done in an ambient temperature and in a plane road (alpha=0, alpha-inclination). The roads considered for testing are tarmac and gravel road.All the testing has been performed in matlab simulation. For the testing three vehicles have been considered which are Toyota, Tesla-s, and Mercedes Benz. All the three vehicles have their own fixed specification i.e. frontal area, air lag, tire radius etc. at last simulation graph has been compared for all three different vehicles and their battery characteristics.***

Keywords: Energy Consumption Rate, Simulation, Battery, Electric Vehicle.

I. INTRODUCTION

The energy consumption of an electric vehicle is a concern when it comes to the safe usage limit without draining out the battery before completion of a journey. The key factor has to be thoroughly profiled before the test run. The study of EV energy consumption can be categorized /divided according to purpose of the EV and EV design and optimization. Taking help of real world measurements has an upper hand in predicting more realistic value for consumption, relying on available data and statistical modelling and is often related to vehicle dynamics and also by the drive train behavior, thus making identification of drive train parameter in energy consumption clearer. This paper is written to diversify the concept by including all possible external parameters linked with vehicle dynamics. The goal here is to find energy consumption rate of three different car models taken in testing. A model that uses real world data compared to cycle test values producing more realistic energy consumption is being analyzed henceforth.

II. CASE STUDY-1

Selection of car model

In this paper three different models of different brand of car are chosen. The selection of car played a vital role for our comparative study of energy consumption. So we took three car model of automobile namely Mercedes Benz CLA-250, Tesla model P85 and Toyota Prius. The main factor for selection of these three car is their efficiency, performance and their acceleration they produce in a small time. Car model selection for the testing purpose include model with combustion engine, hybrid engine and electric engine.
Selected cars suffices to different parameters which provides proper simulation results for ECR calculation. [1]

Mercedes Benz CLA-250- An executive sports car developed and manufactured by Diameter AC(Mercedes Benz). The concept of 2012 came into real life at January 2013 with FF/F4 layout, having a four-cylinder engine rotated 211PS. Its clamed with most aerodynamic production. The data which have been used for estimation can be given as follows in table no.-1:

Table 1: Benz CLA-250 Data

DRAG COEFFICIENT	0.30
FRONTAL AREA	23.2 square feet
DRAG AREA	7.0 square feet
WHEEL RADIUS	0.23

Tesla P85- A full sized electric car with speed, luxury produced by tesla. According to the table (study table) by tesla energy consumption of this model is around 220.9watt hr./km. Tesla S (P85) model is being manufactured in tesla factory in Fremont, California. They use a 3-phase, 4 pole ac inductor 416HP and 443 FE-LB rear mounded electric motor with copper rotor. Having one of the most impressing drag coefficient in automobile industry of Cd=0.24 lesser than any car when released. The table no. 2 shows the parameters deciding the driving torque and speed of Tesla P85.

Table 2: Tesla P85 Data

DRAG COEFFICIENT	0.24
FRONTAL AREA	25.2 square feet
DRAG AREA	6.2 square feet
WHEEL RADIUS	0.24

Manuscript received January 25, 2019.
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Toyota Prius- A full hybrid car manufactured and developed by Toyota since 1997. In initial stages it was offered as 4-door sedan, it has been producedonly as a 5 door lift back from (2003-2015) and then a 5 door FastTrack since 2016. Here the parameters needed for torque-speed calculation are shown in the following table.

Table 3: Toyota Prius Data

DRAG COEFFICIENT	0.26
FRONTAL AREA	23.9 square feet
DRAG AREA	6.2 square feet
WHEEL RADIUS	0.25

III. CASE STUDY2

Drive cycle selection

Driving Cycle can be defined as the series of data point which represents the speed of a vehicle versus time. Various driving cycle are needed for our objective as the power at different instants will according to the load and acceleration. Based on the driving cycle the energy consumed by the battery can be estimated over a certain time period. The driving cycle for highway run and city run are shown in the figures 1 and 2 respectively.

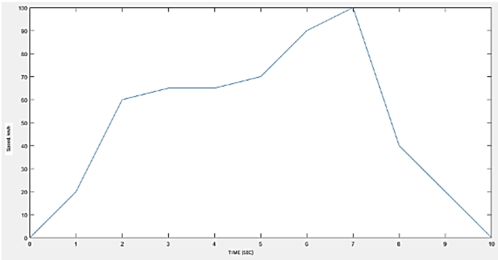

Fig 1: Driving Cycle of Highway Run

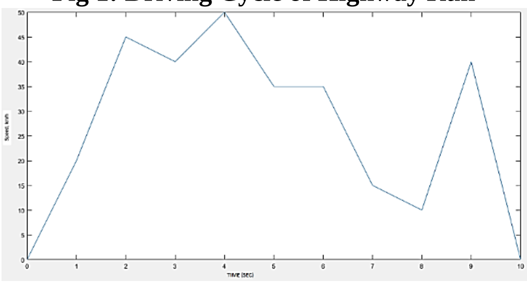

Fig 2: Driving Cycle of City Run

For the objective i.e the energy consumption estimation under this paper we have considered two driving cycles namely CITY RUN and HIGHWAY RUN. As already mentioned that we have taken 3 different car models and for each model we have taken two drive cycles.

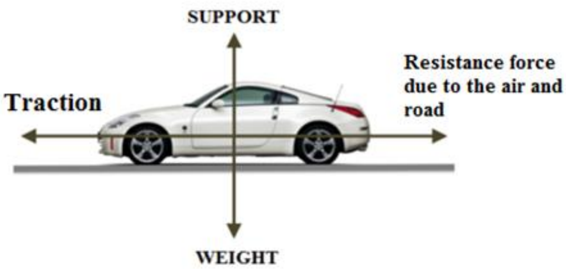

Fig 3: Basic forces acting on a vehicle

The fig 3 show the free body diagram of a vehicle experiencing various forces.

During the highway run of vehicles the speed will be less fluctuating andwill be as compared to the city run. In the above figures the plot for our drive cycles have been shown for one car model under highway and city run.

IV. VEHICLE DYNAMICS

V. THE VEHICLE **dynamics** ANALYSIS CAN BE DONE IN A MULTIDIMENSIONAL APPROACH. THERE ARE SEVERAL FORCES ACTING ON A BODY WHICH AFFECTS THE ACCELERATION OF THE OBJECT. THE ACCELERATION OF AN OBJECT DEPENDS ON:

a) Condition of road
b) Power contribution by the propulsion unit
c) The mass of the vehicle
d) The aerodynamics of the vehicle

General vehicle movement

The motion of a vehicle can be accurately studied by analyzing all the forces on it in the direction of its motion. When a vehicle moves it experiences various opposing forces which tries to retard its motion. These opposing forces are:-

- Rolling resistance
- Aerodynamic drag
- Uphill resistance

From Newton's 2nd law of motion the vehicle acceleration can be expressed as: [2]

$$\frac{dV}{dt}=\frac{\sum F_t-\sum F_{resistac}}{\delta M}$$

where

V = vehicle speed

$\sum F_t$ = total tractive effort $[Nm]$

$\sum F_{resistance}$ = total resistance $[Nm]$

M = total mass of the vehicle $[kg]$

δ = mass factor for converting the rotational inertias of rotating components into translational mass

After analyzing all the forces and resistances the final expression for the net force can be obtained as follows:

$$F_{resistance}=Mgf_r\cos(\alpha)+\frac{1}{2}\rho A_f C_D V^2+Mg\sin(\alpha)+\lambda M\frac{dV}{dt}$$

In the above expression the 1st term represent the rolling resistance where,

M= Mass of the vehicle [kg]

g= acceleration due to gravity

fr= rolling resistance coefficient

α= road angle

The 2nd term represent the aerodynamic drag where,

ρ = air density

Af= Frontal area of vehicle

Cd= Drag coefficient

v= velocity

The 3rd term is the grading resistance. The last term represents the acceleration resistance where,

λ = rotational inertia constant

For running our simulation the inputs given to the motors are torque and revolutions per minute.

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The equations for calculation of power, torque and rpm can be given as follows:

$$Power = Force(N) * velocity(m/s)$$

$$Torque = \frac{9.54 * Power}{\omega(rpm)}$$

$$\omega(rpm) = \frac{velocity(m/s)}{2\pi r}$$

For our estimation the road angle has been considered as zero i.e, the vehicle has been considered to be moving on a plane road. Due to which the grading resistance and the acceleration resistance component have become negligible and the rest calculations has been done using the rest of the parameters.Also for finding the driving cycle for each of the vehicles models two different masses has been considered i.e, for loaded vehicle and unloaded vehicle.

Now after analyzing the forces and deriving the force equation moving on to the simulation part for determining the torque produced under different speed and with different masses.

VI. SIMULATION RESULTS

The following simulation was run and the characteristics were noted in graphical format. The converter module has been followed by a filter setup removing all possible noises and distortions.

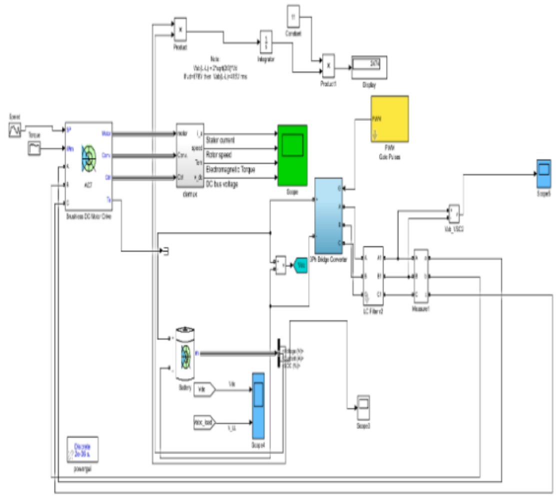

Fig 4: Simulation of model

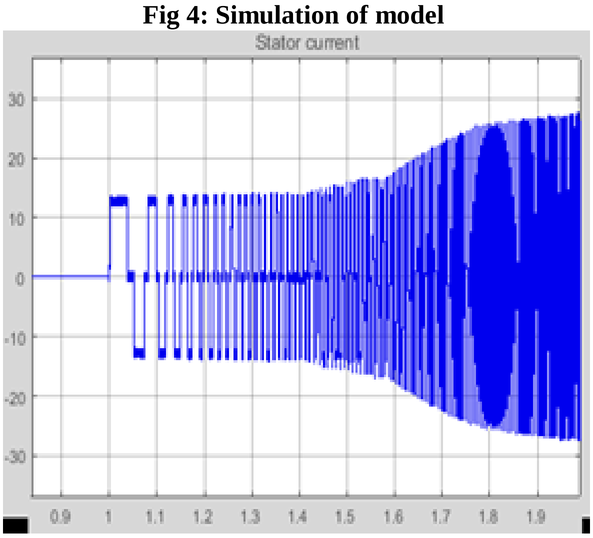

Fig 5: Stator current under highway run

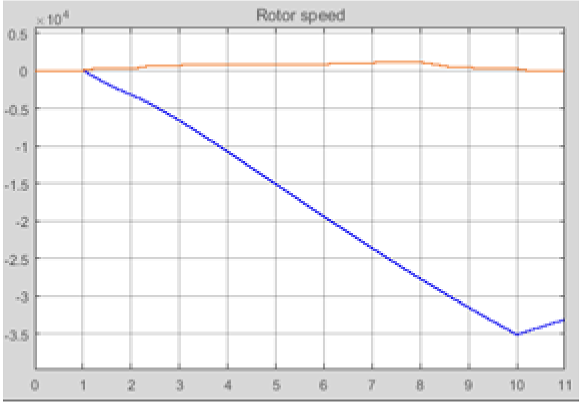

Fig6: Rotor Speed under Highway Run

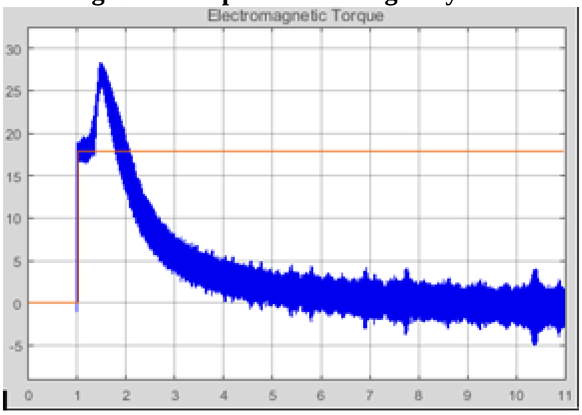

Fig 7: Torque under Highway Run

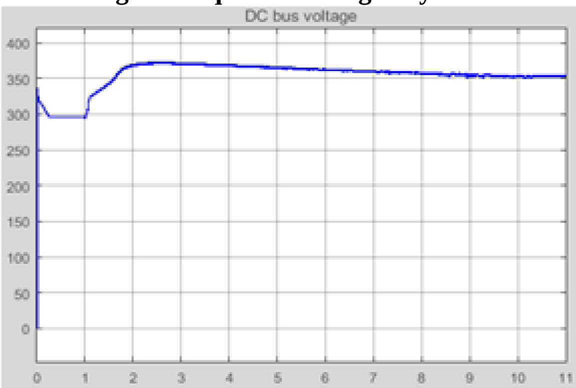

Fig 8: DC Bus Voltage under Highway Run

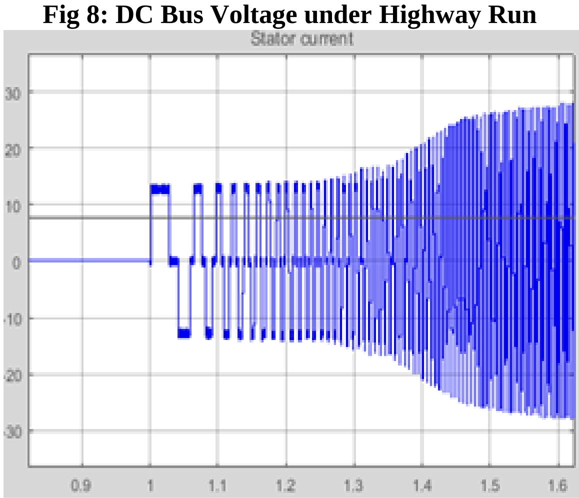

Fig 9: Stator Current under City Run

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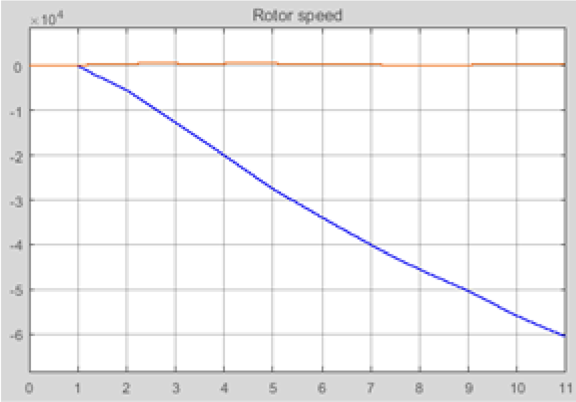

Fig 10: Rotor Speed under City Run

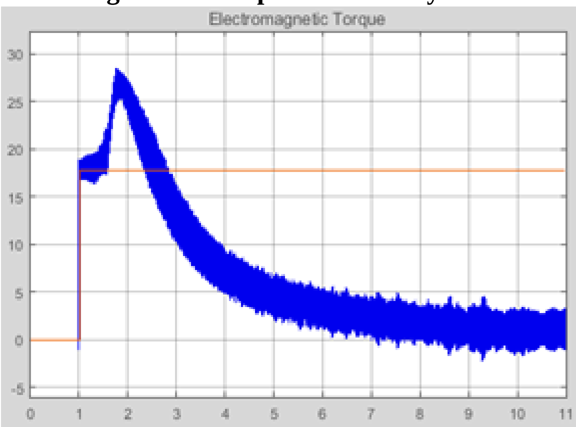

Fig 11: Torque under City Run

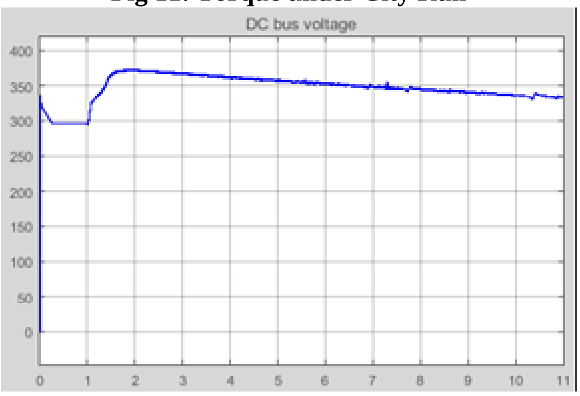

Fig 12: DC Bus Voltage under City Run

The above graph fig 5 and 9 show the analysis of the stator current variations based on the acceleration or we can say based on the driving cycles we have chosen. Similarly fig 6 and 10 shows the rotor speed variations. The fig 7 and 11 are represents the torque experienced by the rotor. And finally the fig 8 and 12 are showing the voltage variations under highway and city run respectively.

The motor torque has been set the reference and the speed and torque values has been fetched.

VII. ENERGY CONSUMPTION RATE

The whole simulation has been run forobtaining the profiling of the energy consumed by the motor during an instant of provided driving cycle. The voltage and current from the scopes have been integrated to provide the power variation over the cycle, and merged onto a display. The current variation was tough to monitor so the power profiling have been opted [3].

Energy E is in Wh. The electric energy consumption is calculated the formula:[5]

C = E / D Where C is expressed in Wh/km, E is Wh and D is the distance covered during the test in km.

Table 4: Comparative Study

TYPE	CAR	MASS	VOLTAGE	ECR(KW)
HIGHWAY RUN	MERCEDES GLA	1530 1766	290 370	8.1 KW 32.4 KW
	TESLA S P85	1700 2170	330 410	28.7 KW 41.4 KW
	TOYOTA PRIUS	1440 2000	380 430	35.9 KW 43.5 KW
CITY RUN	MERCEDES GLA	1530 1766	290 370	10.17 KW 35.9 KW
	TESLA S - 85	1700 2170	330 410	30.6 KW 44.5 KW
	TOYOTA PRIUS	1440 2000	380 430	37.7 KW 46.8 KW

The energy consumed by the vehicles under highway run and city run has been tabulated in the above table for comparative study.

VIII. CONCLUSION

The comparative study provides the virtue with which the energy consumption rate varies with the voltage of battery pack.

The study also depicts the dependency of the energy consumption rate on the chosen driving cycle.

The study and calculationof an accurate energy consumption rate for a chosen distance and car type with its parameters known for observation.

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