



## Sizing and Simulation of Powertrain of Three-Wheeler Electric Vehicle

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### Abstract

This research paper presents the study of designing, modelling and validating the results of simulation of powertrain of 3-wheeler electric vehicle with literature results. According to force and torque requirement at wheels, required power rating of motor is calculated. Indian driving cycle is used to calculate energy consumption by vehicle. Battery chemistry and sizing is selected according to energy requirement. According to requirement of power and constraints, type of motor is selected along with gear reduction calculation to achieve required torque and acceleration. For precise control of motor speed because of road profiles and traffic conditions control strategy is designed. All these subsystems are modelled on simulation platform and comparison with theoretical calculations will be carried out. The objective of this paper is to design, model and optimize the performance of electric vehicle in terms of powertrain and try to match the performance parameters with conventional IC-engine vehicle. This paper comprises of design in gelectric subsystems, creating control strategies for better performance and model-based simulation to check the performance

**Keywords:** Electric Vehicle, Motor Selection, Powertrain, Retrofitment, Simulation

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### 1. Introduction

3-Wheeler is an important means of transportation which contribute to the huge percentage in public and goods transport. With a need for motorized system of transportation the rickshaw has evolved over the years. In this era where petroleum is facing a decline courtesy of non- renewable in nature, electric vehicles will be expected to carry the future mobility. Adding to recent strict emission norms implemented across the world, it is a huge challenge to the automotive manufacturers in reducing the complexity of after treatment devices despite its promising nature to counter emission norms. As compared to conventional ICEthree-wheeler, EV's performance lacks in range, max speed, gradeability etc. Extra weight EV components mainly Battery affects the performance of EV [2]. So, we need to use different strategies in powertrain fore .g., Modification of gear reductions, driveline components controller strategies etc. to enhance performance of electric vehicle to match up with conventional ICE vehicle.

### 2. Retrofitment

It is process of process of converting a combustion engine vehicle into an electric vehicle. It includes replacing conventional powertrain with electric powertrain components [3], [4]. Although designing a retro-fitment kit involves numerous technical and mechanical constraints, it is cheaper than designing a new electric vehicle right from scratch. It also reduces the effective maintenance cost of vehicle. The installation of a retro-fitment kit can alter the designed vehicle dynamics of the vehicle. Also, not all components which are required for retro-fitment kit is indigenously available. Theretro-fitment

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kit/Electric Propulsion Kit as well as retrofitted vehicle must conform to the standards and tests mentioned in AIS-123(Part- 3) [5].

### 3. Benchmarking vehicle data

Benchmarking involves a structured comparison between similar products, services or processes on some dimensions of performance. It can be used to compare the availability and delivery of features in a product. It offers comparison of the performance of vehicle, identification of areas of improvement, setting performance expectations etc.

Table 1: Selected Vehicle Data

<b>Type</b>	Diesel	
<b>Engine</b>	470.5	cc
<b>Max Power</b>	6.74	kW
	3400	@ rpm
<b>Max Torque</b>	23.18	Nm
	2000	@ rpm
<b>Gradeability</b>	18	%
	10.2	deg
<b>GVW</b>	965	kg

### 4. Motor sizing and selection

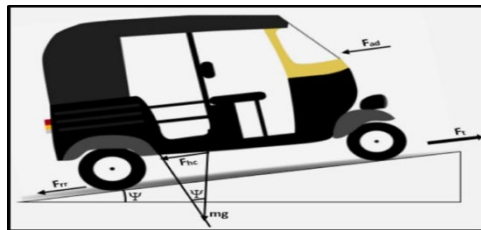


Figure 1: Resistance on Vehicle

The different resistance acting on vehicle are [6]:

1) Rolling Resistance: Rolling Resistance is the opposing force that the vehicle has to overcome due to the rolling motion between the wheels and the surface of motion of the vehicle. It is given by,

$$F_r = f_r mg \cos \alpha$$

Where,  $f_r$  = rolling resistance coefficient of tire,  $\alpha$  = road slope angle.

2) Grade Resistance: Grade resistance is the form of gravitational force. It is the force that tends to pull the vehicle back when it is climbing an inclined surface. It is given by,

$$F_g = mg \sin \alpha$$

3) Aerodynamic Resistance: The resistance offered by air in the atmosphere while vehicle travelling through it is known as aerodynamic drag resistance. It is given by,

$$F_d = \frac{1}{2} \rho C_d A_f v^2$$

Where,  $\rho$  = density of air ( $\text{kg/m}^3$ ),  $C_d$  = Aerodynamic drag coefficient,  $A_f$  = Frontal area ( $\text{m}^2$ ),  $v$  = vehicle speed (m/s).

4) Inertia Resistance: Inertia force is the force that helps the vehicle to reach a predefined speed form

rest in a specified period of time. The motor torque bears a direct relationship with the acceleration force. It is given by,

$$F_i = ma$$

Total resistance acting on vehicle is given by,

$$F_{total} = F_r + F_g + F_d + F_i$$

The power required for motor can be calculated by following formula,

$$P_{ext} = \text{Motor Power (W)} * \eta_d = F_{total} * v \text{ (m/s)}$$

Table 2: Calculation Parameters

$C_d$	0.44	
$\eta_d$	0.8	
$\rho$	1.12	kg/m <sup>3</sup>
$f_r$	0.015	
$A_f$	2	m <sup>2</sup>
$v_{max}$	55	kmph
	15.27778	m/s
$v_{grad}$	5	kmph
	1.388889	m/s
$R_w$	0.24	m

Table 3: Power Calculation

Aerodynamic Resistance	0.95	N
Rolling Resistance	138.89	N
Grade Resistance	1967.24	N
Inertia Resistance	1228.58	N
Total Resistance	3335.68	N
<b>P<sub>motor</sub></b>	<b>5.79</b>	<b>kW</b>

#### 4.1. Power Calculation

Calculations are carried out for different conditions like maximum speed, maximum gradeability and Indian Drive Cycle (IDC). Amongst them, maximum power required for maximum gradeability condition. Power calculation is carried out for maximum gradeability of 10.2° slope at speed of 5 km/hr. Average acceleration is taken as 1.27 m/s<sup>2</sup>.

#### 4.2. Motor Selection

Motor is selected by comparing parameters of different types of EV motors. The motors which are widely used are Permanent Magnet Synchronous Motor (PMSM), Switched Reluctance Motor (SRM), Brushless DC Motor (BLDC) and Induction Motor [7]. The motors are compared on basis of different parameters like efficiency, cost, ease of control, starting Torque, power output, life, maintenance, noise and size [8]. After comparison the specification of selected motor are:

Table IV. Selected Motor Specification

Motor type	PMSM
Voltage Level	48V
Max Torque	42 Nm
Peak Power	7 kW
Max Speed	9000 rpm

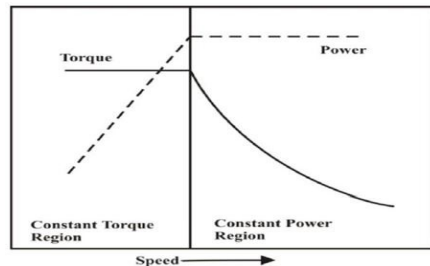


Figure 2: Ideal Torque-Power Curve for EV

### 5. Battery sizing and selection

#### 5.1. Energy Consumption [5]

- a. Considering vehicle running for IDC cycle, the total resistance force on vehicle  $F_{total}$  is 210N.
- b. IDC cycle runs for 3.948km and 648 seconds. The average power consumed by vehicle is given by,  $P_{avg} = F_{total} * V_{avg}$ .
- c. Total energy required can be calculated by integration power consumed over IDC time cycle,  $E_{total} = P_{avg} * (t_{cycle}/3600)$ .
- d. Average energy required per km (IDC) is given by,  $E_{avg} = E_{total} (2-\eta_d)$ .
- e. For designing vehicle for 105 km range, battery capacity of 7.257 kWhr (144 Ah) is required.

### 5.2. Battery Chemistry

Currently NiMH and Li-ion batteries are used in electric vehicles worldwide. NiMH is an old and mature technology[9]. But, due to ability of higher specific energy and specific power, li- ion batteries demand is increasing rapidly. Li-ion batteries provide advantages like low self- discharge rate, smaller in size, faster charging and higher energy density. In 3-W application, due to lack of available space and weight constraints Li-ion batteries are preferred overNiMH batteries.

Table 5: Selected Battery Specifications

Item	Specification
Nominal Energy	3.5 Ah
Pack Voltage	50.8 V
Pack Capacity	144 Ah
Cell Nominal Voltage	3.63 V
Cell Constant Voltage	4.2 V
Cell Cutoff Voltage	2.5 V
Constant Current	1C
Operating Temperature	-20 to 45 °C

### 6. Simulation model

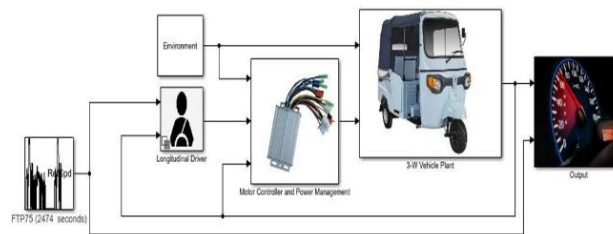


Figure 3: Simulation Model

### 7. Results

- 1. Velocity Profile: FTP-75 profile is fed asinput



Figure 4: Velocity Profile

2. Motor torque:

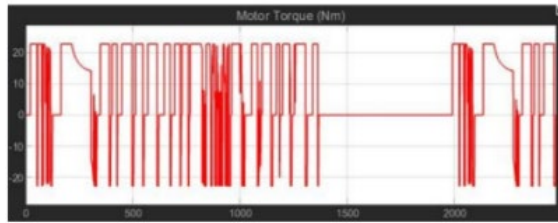


Figure 5: Motor torque profile

3. Motor RPM



Figure 6: Motor RPM

4. Range Comparison: Vehicle is simulated with regeneration and without regeneration mode. Range outputs given by model are compared.

Table 4: Range Comparison

Comparison	Without Regeneration		With Regeneration	
	Theoretical	Practical	Theoretical	Practical
<b>Initial Capacity (Ah)</b>	144	136	144	136
<b>Final Capacity (Ah)</b>	3	10	3	10
<b>Initial SOC%</b>	100	95	100	95
<b>Final SOC%</b>	0	10	0	10
<b>Range (km)</b>	<b>90</b>	<b>77.47</b>	<b>102</b>	<b>89.93</b>

9.

### 10. Validation

For validation of simulation model, reference paper is used and results are compared with reference results to check the accuracy of the model [1]. This paper presents the low-cost EV platform intended to provide a modular and scalable platform for 2 and 3 wheelers that is robust and meets the desired performance characteristics. The paper discusses the integration effort involved and provide a costing perspective for all the components for the electrified drivetrain. The system design, component sizing, simulation activities are explained. The specifications and parameters of vehicle from reference paper are fed to simulation model and their results are compared.

Table 6: Validation Results

Drive Cycle	Range
FTP 75	89.87
NEDC	85.47
WLTP Class 3	87.85
Average Range	87.73
Research Paper Range	100
<b>% Error</b>	<b>12.27 %</b>

## 11. Conclusion

In this work, the literature review on 3-W electric vehicles has been done to study about the modelling methodologies, sizing the components required for vehicle and performance. Initially, a survey is done to study market of Retrofitment technology, available 3-W ICE and electric vehicles. After doing market study, benchmarked vehicle is finalized and target performance parameters are finalized. Motor and battery sizing is done using target parameters, FAME-II standards and analytical calculations. After comparing Permanent Magnet Synchronous Motor (PMSM) and Li-ion battery is shortlisted. Modelling and simulation of vehicle is done and results are compared with calculations. To check whether model works perfectly, results of simulation are compared with research paper results. PMSM of 7kW peak power and 144Ah Li-ion battery pack is selected. Output of model areas follows: **Top Speed:** 10% increase in top speed of retrofitted vehicle as compared to benchmarked ICE vehicle. **Range:** 20% increase in range of retrofitted vehicle as compared to average range of available 3-W electric vehicles. 35% increase in mileage per fuel recharge as compared to benchmarked ICE vehicle. **Gradeability:** Gradeability of 18% was considered while sizing of powertrain components which is almost equal to performance of benchmarked ICE vehicle.

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