Development of a Last Mile Delivery Electric Vehicle

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Abstract: Recent decades have seen a boom in the delivery space, with the increase in online shopping and online food ordering apps. Situation which not only create a pressure on delivery fleet operators, with the need to decrease the cost of operations, but also can be a treat to a sustainable development, means a clean environment as we already know the transportation industry is a large source of pollution.

Thus, there is a need for more suitable vehicles for the delivery space and electric vehicle technology can be the answer. In this work we present the development of a last mile delivery electric vehicle.

Developing a full vehicle is a lot to do, so we focus more on:

- Computing the energy demand of the vehicle
- Battery pack design
- Traction motor
- Vehicle model in SCILAB/XCOS

KEYWORDS: Model Based Design, SCILAB/XCOS, Electric Vehicle, Energy Consumption, Last Mile Delivery, Sustainable development.

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I.INTRODUCTION

In logistics delivery can be classify into two main types: he first mile delivery which consist of transporting the goods from manufacturer to warehouse or warehouse to warehouse and the final mile delivery which deliver the product to the consumer. Both delivery types use different category of vehicles, the first mile use bigger trucks and the last mile use medium or smaller (L4, L5, L5M…) vehicles.

The goal of this work is to develop a full last mile delivery electric vehicle model using the relevant engineering tools needed for the selection or development of each subsystem.

So, to accomplish the above cited goal we use different software as SCILAB for the model-based design, SOLIDWORKS for the vehicle structure design, ANSYS for analysis and LOTUS SHARK for the suspension design.

II-BENCHMARKING

In order to facilitate and accelerate our development time, we benchmarked several delivery vehicles available on the market by studying their technical specifications.

The vehicles selected are either 3 or 4 wheelers with internal combustion engine or electric propulsion.

Bellow tables show models from different manufacturers:

VEHICLE	MOTOR TYPE	MAX POWER (KW)	MAX TORQUE (Nm)	TOP SPEED (km/h)	DIMENSIONS(mm)				VEHICLE WEIGHT (kg)		BATTERY PACK			RANGE (km)	GRADE-ABILITY
					L*	W*	H*	Wb*	KERB WEIGHT	GVW*	TYPE	CAPACITY (KWh)	VOLTAGE (V)		
ALKè ATX 340E	48V AC asyn* induction electric motor	14	113	44	3550	1650	1980	2130	1-(1170) 2-(875)	2150	1-(Lead acid) 2-(Lithium LiFePO4)	1-(14.4) 2-(10)	48	1-(119) 2-(86)	30%
PAXTER L7e-CU	3-phase PMAC	7.48	38	60	2290	1180	1860	1530	420	845	LiFePo4	8.1	48	135	18%
GARIA UTILITY SC MODEL	BRUSH-LESS AC	11		55	3269	1313	1863	2117	763	1350	LiFePo4	10.2	48	85	25%
MAHIN-DRA TREO ZHOR		8	42	50	3100	1460	2175	2216	495	995	Lithium ion	7.37	48	118	7°
Kinetic Safar Shakti	BLDC	1.5		35	2837	1100	1820	2118	390	790	Lithium ion	5.76	48		10°
OMEGA SEKEI RAGE+		4.8		45	3200	1475	1710		480	960	Lithium ion	7.5	48	70-80	16%
LOHIA NARAIN CARGO	BLDC	1.95		25	2790	1000	1800	2040	320	640	Lithium ion	5.04	48	100	

Table 1: Electric vehicles specification

VEHICLE	ENGINE	MAX POWER (KW)	MAX TORQUE (Nm)	TOP SPEED (km/h)	DIMENSIONS(mm)				CARGO BED(mm)	GROUND CLEAR-ANCE(mm)	VEHICLE WEIGHT (KG)		GRADE-ABILITY
					L*	W*	H*	Wb*			KERB WEIGHT	GVW*	
MAHINDRA GIO	441.5 CC	6.8 ± 0.3 Kw @ 3600 rpm	21 Nm @ 2400 rpm	40	3180	1460	1815	2005	1570*1460*380	180	610	1110	
PIAGIO APE EXTRA LD	436 CC	5.52 Kw @ 3600 rpm	18 Nm @2400	60	3145	1490	1750	2100	1660 X 1400	240	438	975	22.16%
MAHINDRA ALFA PLUS	436 CC	5.52 Kw @3600 rpm	18 Nm @2400	54	3175	1460	1700	2165	1730x1460 x320	175	490	995	
ATUL SHAKTI CARGO	598 CC	7 kw(9.38 hp) @ 3600 rpm	23.5 Nm @ 2000 ± 200 rpm		3328	1550	1830	2110				1020	
ATUL GEM	435 CC	6 kW @ 3600 rpm	21 Nm @ 2200		2930	1450	1830	1925			420	995	
BAJAJ MAXIMA C DIESEL	470.5 CC	6.74 Kw @ 3400 rpm	23.18 Nm @ 2000 rpm		3230	1493	1818	2125		193	535	965	18%

Table 2: IC vehicles specifications

Engine		**Wheels and tyres**	
Type	Single Cylinder, Direct Injection	Tyre size	4.50 - 10 LT 8PR
Bore x stroke (mm)	86 X 76	Tyre pressure (Kg/Cm Square)	Front 1.8 & rear 4.0
Displacement (cc)	441.5	**Electrical system**	
Compression ratio	20.3:1	System voltage (V)	12 DC
Max. Engine output (kW @ rpm)	6.8 ± 0.3 kW @ 3600 rpm	**Fuel tank capacity (L)**	10.5
Max. Torque (Nm @ rpm)	21 ± 1 Nm @ 2000 - 2400 rpm	**Dimensions**	
Clutch		Wheel base (mm)	2005
Type	Multi plate wet type clutch	Overall width (mm)	1460
Gear box		Overall length (mm)	3180
Type	Sequential shift, Constant mesh gear box	Overall height (mm)	1815
No. of gears	4 forward, 1 reverse	Front track (mm)	1060
Suspension		Rear track (mm)	1260
Type / Description		Min. ground clearance (mm)	180
Front:	Independent Suspension with Mc-pherson strut	Cargo box dimensions (mm)	1570 X 1460 X 380
Rear:	Leaf spring with Telescopic shock absorber	**Weights**	
Brakes		Maximum GVW (kg)	1110
Front and Rear brake	Hydraulic, Drum	Kerb weight (kg)	610
Parking brake	Internal expanding type on rear wheels, hand lever cable type	**Turning radius** (m)	3.8
		Seating capacity	D & D+1

Table 3: Mahindra Gio Specifications

L* = Overall length Wb* = WheelBase
W* = Overall Width GVW* = Gross VehicleWeight
H* = Overall Height

BY looking the data in the tables, we can see that the manufacturers used different motor types and the most common one is the brushless electric machine with DC or AC configuration. The battery pack is either lead-acid or lithium -ion and the 48 V is a kind of standard for the pack voltage.

The max power column tells us the minimum power requirement in the class of vehicles selected is 1.5 KW.

Mahindra Gio is a nice compact IC vehicle develop by Mahindra with specification as shown in the table 3:

For further simplification we consider the GIO as a reference vehicle.

As seen above the acceleration time (time taken to reach max speed) is not mention by the manufacturer. we can try to calculate it since we have the max speed and the vehicle weight.

Taking the vehicle mass= (vehicle Kerb weight x mass factor + driver weight) = (610*1.05+80) =720 kg, the

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coefficient of friction between the vehicle tires and the road as 0.5 and the max vehicle speed =40 km/h (11.11 m/s) we have:

$F = \mu_t W$

$= \mu_t m a_g$

were

F = friction force between vehicle wheel and the road (N)

μ_t *= friction coefficient between the wheel and the surface or road*

W = weight or vertical force between wheel and surface (N)

m = mass on the wheel (kg)

a_g *= acceleration of gravity (9.81 m/s²)*

$F_{one_wheel} = 0.5 ((720*9.81) / 4)$

$= 883 N$

The fricion force from both driving wheels

$F_{both_wheels} = 2 *883$

$= 1766 N$

The **maximum acceleration** of the vehicle under these conditions can be calculated with Newton's Second Law as:

$A_{veh} = F / m$

$= 1766 / 720$

$= \mathbf{2.45\ m/s^2}$

$= (2.45\ m/s^2) / (9.81\ m/s^2)$

$= 0.25\ g$

were

a_{veh} *= acceleration of the vehicle (m/s²)*

The minimum time to accelerate from *0 km/h* to *40 km/h* can be calculated as

$dt = dv / a_{veh}$

$= ((40\ km/h) - (0\ km/h)) * (1000\ m/km) * (1/3600\ h/s) / (2.45\ m/s^2)$

$= \mathbf{4.53\ s}$

were

dt = time used (s)

dv = change in velocity (m/s)

Traction force required

Using again Newton's Second Law we have:

$F_{tract} = m_{veh} * a_{veh}$

$=720*2.45$

$=1764$ N

Were

F_{tract}= traction force (force used to generate motion between the vehicle and the road)

M_{veh}= vehicle mass

Assuming there is no slippage between the road and wheels, Since the available friction force is greater than the total traction force, the total traction force can be applied at the wheels in order to achieve the 0-40 km/h in 4.53 s.

so, considering we are developing the electric version of the Mahindra GIO our target design specifications are as follows:

Battery

- **Nominal voltage:** 48V
- **Chemistry**: Lead-Acid or Lithium-Ion

Powertrain

- **Electric motor type**: BLDC motor
- **Vehicle Range:** 100 km
- **Top Speed:** 40 km/h
- **Time 0-40 km/h:** 4.53 s
- **Kerb weight**: 610 KG

III-POWER REQUIREMENT AND ENERGY CONSUMTION DETERMINATION

The goal in this section is to compute the total resistive force, the power requirement of the vehicle and the average energy consumption of the vehicle which is use for the battery pack design.

For the power requirement we can go with the max power of our reference vehicle Mahindra Gio which is 6.8 KW, let say 7 KW. Otherwise, we should compute it using the vehicle mass, linear velocity and the different road loads acting on the vehicle.

Now we can compute the **average energy consumption**. The energy consumption can be compute using SCILAB and an homologation cycle or drive cycle. There are many drives cycle available like:

- The NEDC (New European Drive Cycle)
- The WLTP (Worldwide harmonized Light vehicles Test Procedure) drive cycle
- IDC (Indian Drive Cycle)
- FTP-75

In this work we are using the WLTP cycle which combine 3 drive cycles as below:

- Class 1 – low power vehicles with PWr<= 22
- Class 2 – vehicles with 22 <PWr<= 34
- Class 3 – high-power vehicles with PWr> 34

Were:

PWr (kW/Tons or W/KG) is the power-to-weight ratio, defined as the ratio between the rated engine or motor power and kerb weight of vehicle.

$$PW_r = \frac{Pmax}{m_v}$$

So, replacing our reference vehicle kerb weight and max power into above formula we have:

$$PW_r = \frac{7}{0.61} = 11.48$$

Since the vehicle's PWr is below 22, we are using the WLTP Class 1 driving cycle to calculate the energy consumption.

The remaining process is straight forward, first of all we load the drive cycle into the SCILAB environment, then with a SCILAB scripts and SCILAB/XCOS block diagram the simulations is done to find out the Total resistive force, the average energy consumption on the chosen drive cycle.

Class 1 vehicles: ratio of rated power in W / kerb mass in kg <= 22

For further requirements/recommendations see table "Explanations"

Phase	Total elapsed time	Phase elapsed time	WLTC class 1, version 1.4, vehicle speed	WLTC class 1, version 1.4, acceleration	WLTC class 1, version 1.4, acceleration		duration	stop duration	distance
	s	s	km/h	m/s²	km/h/s		s	s	m
Low	0	0	0.0	0.00	0.00	low	589	155	3324
Low	1	1	0.0	0.00	0.00	medium	433	48	4767
Low	2	2	0.0	0.00	0.00		**1022**	**203**	**8091**
Low	3	3	0.0	0.00	0.00				
Low	4	4	0.0	0.00	0.00				
Low	5	5	0.0	0.00	0.00				
Low	6	6	0.0	0.00	0.00				
Low	7	7	0.0	0.00	0.00				
Low	8	8	0.0	0.00	0.00				
Low	9	9	0.0	0.00	0.00				
Low	10	10	0.0	0.00	0.00				
Low	11	11	0.0	0.03	0.10				
Low	12	12	0.2	0.43	1.55				
Low	13	13	3.1	0.76	2.75				
Low	14	14	5.7	0.68	2.45				
Low	15	15	8.0	0.61	2.20				
Low	16	16	10.1	0.56	2.00				
Low	17	17	12.0	0.51	1.85				

Table 4: WLTP Class 1

Duration: 1022 s
Distance: 8091 m = 8.091 km

```
clear()
clc()
//Decode ole file, extract and open Excel stream
[fd,SST,Sheetnames,Sheetpos] = xls_open('WLTP-DHC-12-07e.xls');
//Read second data sheet
[Value,TextInd] = xls_read(fd,Sheetpos(4));
//close the spreadsheet stream
mclose(fd);
//load WLTP time and speed values in structure
WLTP.time = Value(8:1030,3);
WLTP.values = Value(8:1030,5);
//plot WLTP speed profile
plot(WLTP.time,WLTP.values)
xgrid()
xlabel("Time [s]")
ylabel("Vehicle speed [km/h]")
title("Last Mile EV Development")
```

Figure 1: Loading WLTP excel file into SCILAB environment

Here 4 is the position of WLTP Class 1 in the excel file, 8 and 1030 are the first row and last row with values in WLTP Class 1, 3 represent the elapsed time values column and 5 the speed values column.
Note: all the SCILAB/XCOS files should be saved in the same folder with the WLTP excel file for the simulationto work.

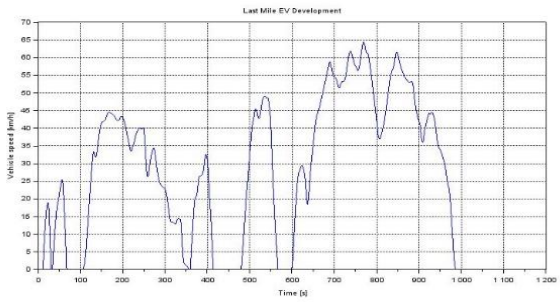

Figure 2: WLTP Class 1 Drive Cycle Profile

Mathematical expressions needed for energy consumption computation

The energy consumption is computed based on the road loads. The total road load force F_{tot} (N) is the sum of the Inertial force, Gradient or Road slope force, Rolling resistance force and aerodynamic drag force.

$$F_{tot} = F_i + F_s + F_r + F_a$$

where:

- Fi – inertial force
- Fs – road slope force
- Fr – road load force
- Fa – aerodynamic drag force

The unit of all the forces is Newton (N)

Inertial force:

$$F_i = m_v * a_v$$

where:

- m_v (kg) – total vehicle mass
- a_v (m/s²) – vehicle acceleration

vehicle acceleration can be calculated as:

$$a_v = \frac{\Delta v}{\Delta t}$$

where:

- Δ_v (m/s) = final speed -initial speed
- Δ_t (s) = final acceleration time – initial time

Gradient force:

$$F_s = m_v * g * sin(\alpha_s)$$

where:

- g (m/s²) – gravitational acceleration
- αs (rad) – road slope angle

Rolling resistance force:

$$F_r = m_v * g * c_{rr} * cos(\alpha_s)$$

where:

- c_{rr} – road rolling resistance coefficient

Aerodynamic drag force:

$$F_a = \frac{1}{2} * \rho * c_d * A * v_v^2$$

where:

- ϱ (kg/m³)– air density at 20 °C
- cd – air drag coefficient
- A (m²) – vehicle frontal area
- V_v (m/s)– vehicle speed

Total Power:

$$P_{tot} = F_{tot}^{*} * v_v$$

The total power (P_{tot}(watt) is the product between the **Total Road forces (N)** or Traction forceandthe vehicle speed (m/s)

The **Total Energy consumption** is obtained by integrating the total power over time (for the whole duration of the cycle,1022 s for WLTP class 1)

$$E_{tot} = \int P_{tot} * dt$$

The above mathematical expressions are implemented in the SCILAB/XCOS block diagram in order to compute the energy consumption of the vehicle over the drive cycle.

Before running the simulation in XCOS, the vehicle parameters are given in a SCILAB script as shown figure 3:

```
vehMassKerb =610; // [kg]
vehMassDriver = 80; // [kg]
vehMassfm = 1.05; // Vehicle mass factor due to inertia force [-]
vehMass = vehMassKerb * vehMassfm + vehMassDriver; // [kg]
vehg = 9.81; // [m/s^2]
vehcd = 0.8; //Drag coefficient [-]
vehfa = 2.6; // Frontal Area[m^2]
vehro = 1.204; // Air density at atmospheric pressure[kg/m^3]
roadSlope = 0.0524; // [rad]
roadCrr = 0.015; // [-]
Wheel_R = 0.268; // wheel radius [m]
Gear_Ratio =10; // Transmission gear Ratio
Teff = 0.85;     // Transmission Efficiency
```

Figure 3: Vehicle parameters

To perform the simulation, the final integration time is set to 1022 (WLTP Class 1 duration) in the simulation set up dialog box and the clock in the XCOS block diagram is set to 1 s which is the WLTP elapsed time.

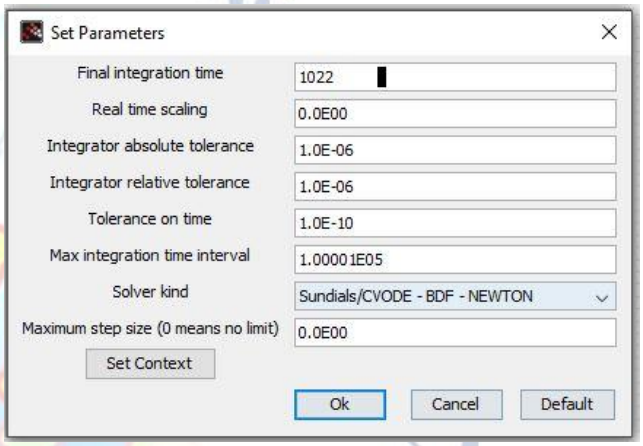

Figure 4: Simulation set up

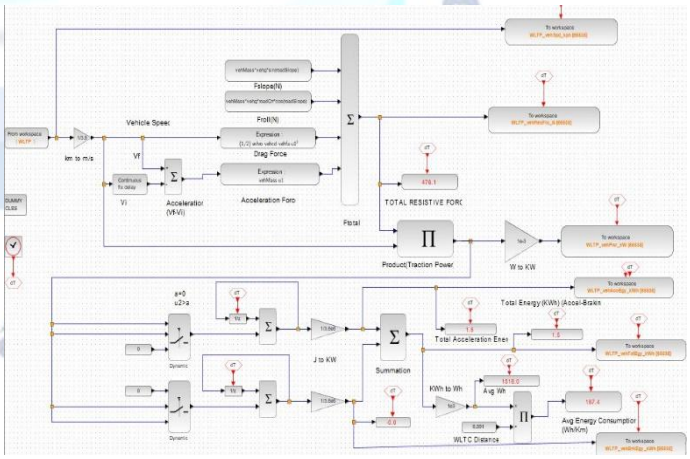

Figure 5: XCOS block diagram for computing energy consumption

Performing the simulation for the given vehicle parameters, the average energy consumption of the vehicle is 187.4 Wh/km and the acceleration, braking and total energy vs time plot is shown below:

```
plot(WLTP_vehTotEgy_kWh.time, WLTP_vehTotEgy_kWh.values,'k')
plot(WLTP_vehAccEgy_kWh.time, WLTP_vehAccEgy_kWh.values,'r')
plot(WLTP_vehBrkEgy_kWh.time, WLTP_vehBrkEgy_kWh.values,'b')
xgrid()
xlabel('Time [s]','FontSize',2)
ylabel('Energy [kJ]','FontSize',2)
title('last Mile EV Development','FontSize',2)
legend('Total Energy','Acceleration','Braking',2)
```

Figure 6: Data post processing

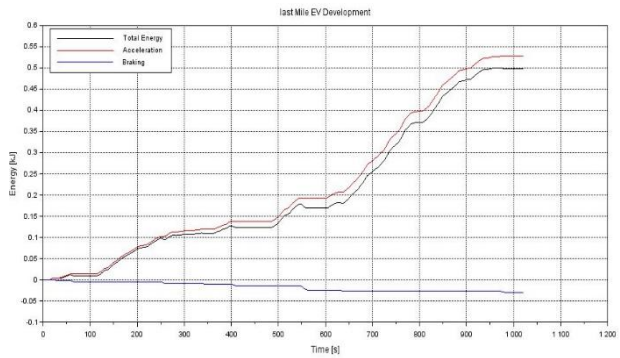

Figure 7: Acceleration, Braking and Total energy vs time graph

IV-BATTERY PACK DESIGN

The battery pack is the heart of a Battery Electric vehicle (BEV), the complete vehicle is design around it, because all the key specifications of the vehicle like:

Traction Motor torque, vehicle range, weight and also price depend on the battery pack. So, the battery pack need to be design with care.

In our work above, we compute the average energy consumption of the vehicle due to road loads, but in a vehicle, we also have auxiliary components (12 V electrical system, heating, cooling etc.) which demand energy to function. So, we need to take that energy demand into account for deciding the average energy our battery pack should supply.

On average in a typical vehicle the auxiliary systems use 430 W of electrical power. Calculating that consumption over the duration of WLTP class 1 (1022 s = 0.28h), we have 430*0.28 = 120.4 Wh, now dividing that consumption over the length of our Drive cycle (8091 m = 8.091) we have 120.4/8.091 = 14.88 Wh/Km

Over the length of the WLTP Class 1, the average energy consumption of auxiliary systems of our vehicle is 14.88 Wh/km.

We can now calculate the Total average energy consumption which is the combination of energy consumption due to road loads and auxiliary systems energy consumption taking into account the energy losses from battery pack to wheels.

Below formula is use:

$$E_{avg} = (E_p + E_{aux}) * (2 - \eta_p)$$

Where:

E_{avg} = Average energy consumption

E_p = Energy need for propulsion (energy consumption due to road loads)

E_{aux} = Auxiliary systems energy consumption

η_p= Efficiency of power converters from battery to wheels.

Taking efficiency of power converters as 90% and substituting the values in the formula we have:

E_{avg}= (187.4+14.88) * (2-0.9)

E_{avg}= 222.5 Wh/Km

We are designing our battery pack for an average energy consumption of
222.5 Wh/Km.

Battery pack design calculations

In order to perform our battery pack calculations, we need to go from the battery cell which is the basic or building element of the pack. The battery cells differ in terms of chemistry, voltage, ampere-hour, shape and manufacturer.

Below are the specifications of cells from different manufacturers:

Manufacturer	Panasonic	A123-Systems	Molicel	A123-Systems	Toshiba	Kokam
Type	cylindrical	cylindrical	cylindrical	pouch	pouch	pouch
Model	NCR18650B	ANR26650m1-B	ICR-18650K	20Ah	20Ah	SLPB7570270
Length (m)	0.0653	0.065	0.0652	0	0	0
Diameter (m)	0.0185	0.026	0.0186	0	0	0
Height (m)	0	0	0	0.227	0.103	0.272
Width (m)	0	0	0	0.16	0.115	0.082
Thickness (m)	0	0	0	0.00725	0.022	0.0077
Mass (kg)	0.0485	0.076	0.05	0.496	0.51	0.317
Capacity (Ah)	3.2	2.5	2.6	19.5	20	15.6
Voltage (V)	3.6	3.3	3.7	3.3	2.3	3.6
C-rate (cont.)	1	10	1	1	1	2
C-rate (peak)	1	24	2	10	1	3

Table 5: Battery cell specification from different manufacturer

The cells specifications can be summarized in terms of energy, volumetric and gravimetric density using the following formulas:

Cell volume:

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- cylindrical cells, V_{cc} (m^3)

$$V_{cc} = \frac{\pi D^2_{bc}}{4} * L_{bc}$$

where:
D_{bc} (m) – battery cell diameter
L_{bc} (m) – battery cell length

- pouch cells, V_{pc} (m^3)

$$V_{pc}=H_{bc}*W_{bc}*T_{bc}$$

where:
H_{bc} – battery cell height (m)
W_{bc} -battery cell width (m)
T_{bc} -battery cell thickness (m)

battery cell energy E_{bc} (Wh):

$$E_{bc}= C_{bc}*U_{bc}$$

where:
C_{bc} – battery cell capacity (Ah)
U_{bc} – battery cell voltage (V)

Battery cell energy density:

- volumetric energy density u_v (Wh/m^3)

$$u_v = \frac{E_{bc}}{V_{cc}}$$

- gravimetric energy density u_G (Wh/kg)

$$u_G= \frac{E_{bc}}{m_{bc}}$$

So, using the formulas the manufacturers cells are summarized as shown in table 6:

Manufacturer	Panasonic	A123-Systems	Molicel	A123-Systems	Toshiba	Kokam
Type	cylindrical	cylindrical	cylindrical	pouch	pouch	pouch
Model	NCR18650B	ANR26650m1-B	ICR-18650K	20Ah	20Ah	SLPB7570270
Energy (Wh)	11.52	8.25	9.62	64.35	46	56.16
Volume (l)	0.017553	0.03451	0.017716	0.26332	0.26059	0.171741
Energy density gravimetric (Wh/kg)	237.53	108.55	192.4	129.74	90.2	177.16
Energy density volumetric (Wh/l)	656.31	239.06	543.01	244.38	176.52	327

Table 6: Summarized Battery cells specifications

From above cells we are choosing the Panasonic battery cell for the design of our battery pack.
Now that the specifications about the battery cell are clear we can continue with the pack design calculations and the work goes as follows:

Cell Module or StringBattery Pack

Required Battery pack Total Energy (E_{bp}):

$$E_{bp}=E_{avg}* R_v$$

Where:
E_{avg}- Average energy consumption (Wh/Km)
R_v-Vehicle range (Km)
From our target design specification, we have R_v= 100 km and E_{avg}= 222.5 Wh/Km
E_{bp}= 222.5 * 100
E_{bp}= 22250 Wh/Km = 22.25 Kwh/Km

Number of battery cells connected in series (Ncs):

$$N_{cs}= U_{bp} / U_{bc}$$

Where:
U_{bp}- Nominal Battery Pack voltage (V)
U_{bc}– Battery cell Voltage (V)

From our benchmarking we decided to take the nominal battery pack voltage as 48V and the Panasonic model NCR18650B cell voltage = 3.6 V.

N_{cs}= 48/3.6
N_{cs}= 14 cells

Energy content of a Module (E_{bm}):

$$E_{bm}= N_{cs} * E_{bc}$$

Where:
E_{bc}– Energy of a battey cell (Wh)
From the Summarized Battery cells specifications table, we have the Panasonic battery cell energy equal to 11.52 Wh.
E_{bm}= 14 * 11.52
E_{bm} = 161.28 Wh

Total number of modules of the battery pack (N_{pm}):

$$N_{mp}= E_{bp}/ E_{bm}$$

Where:
E_{bp}– Required battery pack total energy (Wh)

N_{mp}= 22250 /161.28
N_{mp} = 138 Modules

Having the number of modules in the pack and the energy content of each module we can calculate the Total energy of the Battery pack as a product between both, which give us **E_{bp} = 138 * 161.28 = 22.26 Kwh**

Battery pack capacity (C_{bp}):

C_{bp}= N_{mp} * C_{bc}
Where:
C_{bc}– cell capacity (Ah)
C_{bp}= 138 * 3.2
C_{bp}= 441.6 Ah

Number of cells of the battery pack (N_{cp}):

N_{cp}= N_{mp}* N_{cs}
N_{cp}= 138 * 14
N_{cp}= 1932 cells

Mass of Battery Pack (m_{bp}):
m_{bp}= N_{cp}* m_{bc}
Where:
m_{bc}– mass of one battery cell (kg)

We have the Panasonic cell mass equal to 0.0485kg
M_{bp}= 1932 * 0.0485
M_{bp}= 93.7 kg
Volume of the battery pack (V_{bp}):

V_{bp}= N_{cp}* V_{bc}
Where:
V_{bc} – Volume of one battery cell
V_{bp}= 1932* 0.017553
V_{bp}= 33.91 m^3

It should be noted that this is the mass and volume of the battery pack without the additional part like bus bars and the electronics.

Module Peak Current (I_{mpc}):

I_{mpc}= Peak C-rate$_{bc}$* C_{bc}
I_{mpc}= 1 * 3.2
I_{mpc}= 3.2 A

Battery Pack Peak Current (I_{bpp}):

I_{bpp}= I_{mpc}* N_{mp}
I_{bpp}= 3.2 * 138
I_{bpp}= 441.6 A

Battery pack peak power (P_{bpp}):
P_{bpp}= I_{bpp}* U_{bp}
P_{bpp}= 441.6 * 48
P_{bpp}= 21.2 kW

Module Continuous Current (I_{mcc}):
I_{mcc}= Continuous C-rate$_{bc}$* C_{bc}
I_{mcc}= 1 * 3.2
I_{mcc}= 3.2 A
Battery Pack Continuous Current (I_{bpc}):
I_{bpc}= I_{mpc}* N_{mp}
I_{bpc}= 3.2 * 138
I_{bpc}= 441.6 A
Battery pack Continuous power (P_{bpc}):
P_{bpc}= I_{bp}* U_{bp}
P_{bpc}= 441.6 * 48
P_{bpc}= 21.2 kW

The battery pack specifications are summarized in table 7:

PARAMETERS	RESULTS
Cells in series	14
Module Energy (Wh)	161.28
Number of Modules	138
Pack Capacity (Ah)	441.6
Number of cells in Pack	1932
Mass (Kg)	93.7
Volume (m^3)	33.91
Module Peak Current (A)	3.2
Pack Peak Current (A)	441.6
Pack peak Power (kW)	21.2
Module continuous Current (A)	3.2
Pack Continuous Current (A)	441.6
Pack Continuous Power (kW)	21.2

Table 7: Battery Pack Specifications

From these specifications the battery pack development can continue with the State of Charge (SOC), Depth of Discharge (DoD) simulation, Thermal Management,

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Mechanical and the Battery Management System (BMS) design.

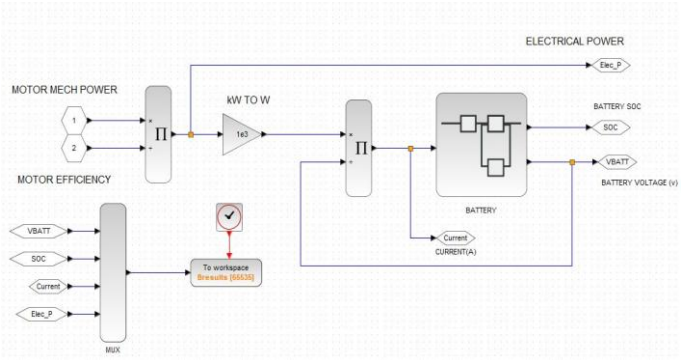


Figure 8: Battery model in XCOS

V-ELECTRIC MOTOR

The electric motor is the power delivering unit of the battery electric vehicle (BEV). It receives electrical energy from the battery and convert it into mechanical energy to run the vehicle down the road. While developing a BEV, the electric machine can be selected in two ways:

- Design the motor from scratch for the application
- Selecting from existing machines available on the market.

Designing from scratch maybe a good fit for big OEMs, for small scale production or prototyping selection from market is a suitable development decision.

As already mention in the target design specifications, we are using a BLDC (Brushless Direct Current) motor, decision which is made based on the benchmarking of existing vehicles develop by some manufacturers.

The next question is how do we select among the 100 of BLDC available?

Well, the motor can be selected based on the design requirements which are used as guide to filter motors based on their characteristics (Max Power, Torque, Speed, Efficiency etc.).

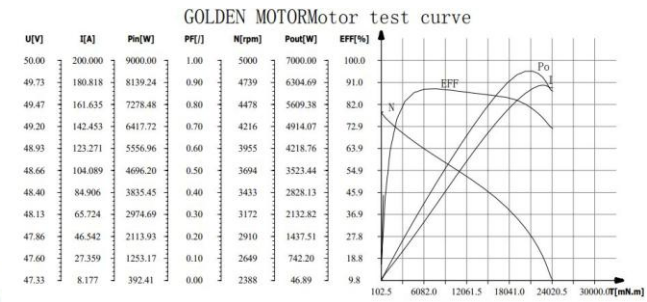
Motor characteristics can then be validated by running a dynamic simulation of the motor in SCILAB/XCOS. The simulation is a way also to understand the influence of the motor on the battery state of charge (SOC).

In this case the motor, battery, transmission and chassis models are built, then associated to form a vehicle model, which is run on a drive cycle.

This simulation can be run for different motor and choose the appropriate one.

For this work, by searching for supplier of BLDC motor, we found **GOLDEN Motor,** company which supply BLDC motor of different sizes with details specifications.

The HPM48-5000 is suitable for our application and the specifications of this motor are shown in table 8:



Description	voltage (V)	current (A)	P. input (W)	torque (mN. m)	rotate (RPM)	P. output (W)	eff (%)
Upload point	47.99	8.177	392.41	360.0	4389	165.45	42.2
Most efficiency point	47.57	73.689	3500.65	7728.8	3861	3096.05	88.4
Max Po. point	47.34	175.436	8307.60	21276.9	2892	6661.91	80.2
Max torque point	47.42	176.418	8366.97	24117.9	2389	6033.82	72.1
End point	47.42	176.430	8367.19	24122.5	2388	6031.89	72.1
Rated rotate point	47.38	132.885	6296.72	14540.5	3476	5421.21	86.1

Table 8: Golden motor HPM48-5000 BLDC motor specification

So, using these specifications the electric motor model can be modelled and simulate in SCILAB/XCOS.

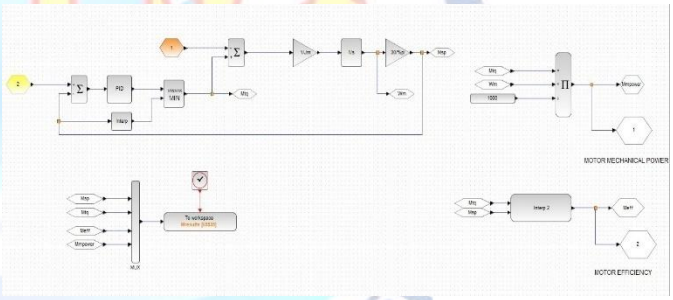


Figure 9: Electric motor model with a simple PID controller

Combining the electric motor model with other subsystems (chassis, transmission and battery) as we will do later the motor torque, speed power and it influence on battery state of charge (SOC) can be plot for a given drive cycle.

VI-VEHICLE MODEL IN XCOS

Now that we have the electric motor and the battery specifications and their blocks in XCOS these data are combine and a complete vehicle model is built, means chassis, transmission, electric motor and battery.

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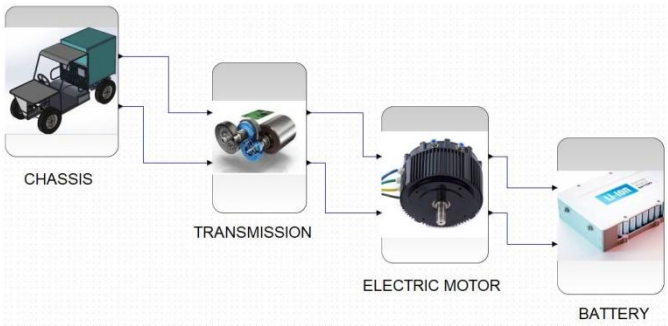

Figure 10: Electric vehicle Model In XCOS

In the above model the transmission or Gear Box can be single, double speed or direct drive with high final gear ratio. This is due to the fact that the electric motor has high starting torque and that torque can be consistent even at high rpm of the motor, so the vehicle does not need multi-speed gearbox to operate efficiently.

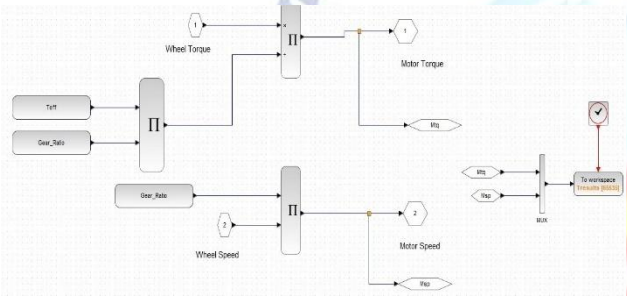

Figure 11: Transmission model in XCOS

The chassis model is where the drive cycle is loaded into the model and the resistive forces are computed to find the total road load or traction force. From the traction force the wheel torque is found, the wheel speed from the drive cycle and the process goes to the transmission. This block can be use also to find the power needed to propel the vehicle, since propulsion power is the product between traction force and vehicle speed.

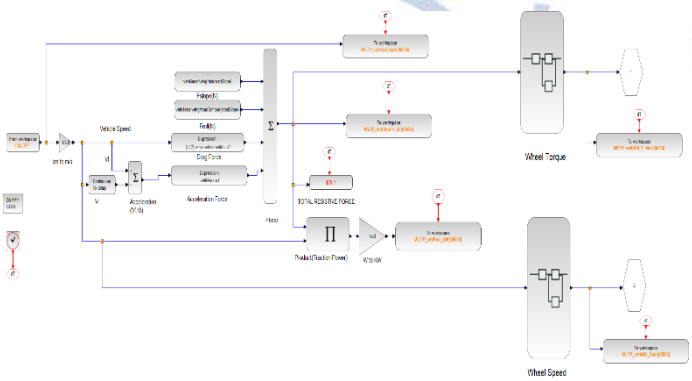

Figure 12: Chassis model in XCOS

The model being ready, the WLTP is used to simulate the model in order to analyze the performance of each subsystem.

The post processing figures are shown in figures (13,14,15,16,17,18,19)

Figure 13: Electric Motor Speed

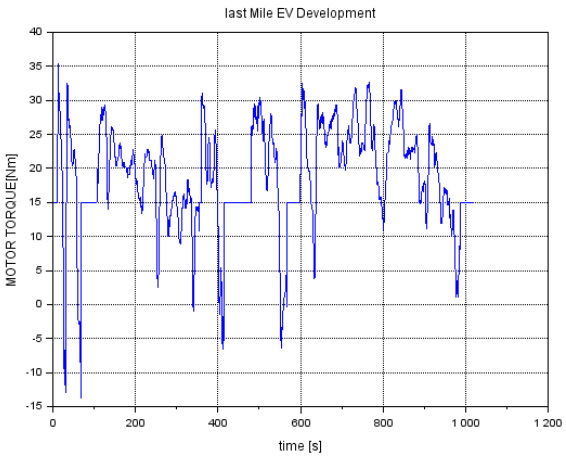

Figure 14: Motor Torque

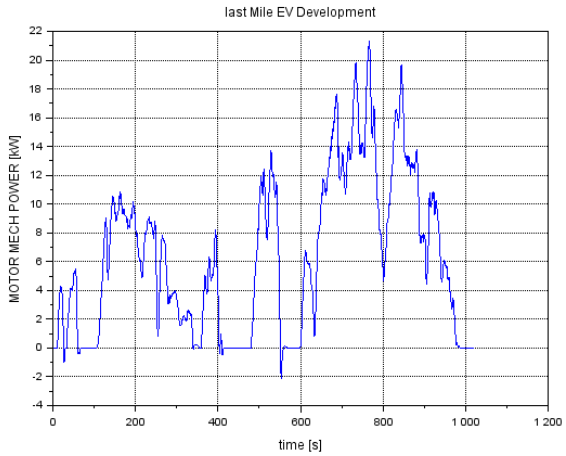

Figure 15: Motor Mechanical Power

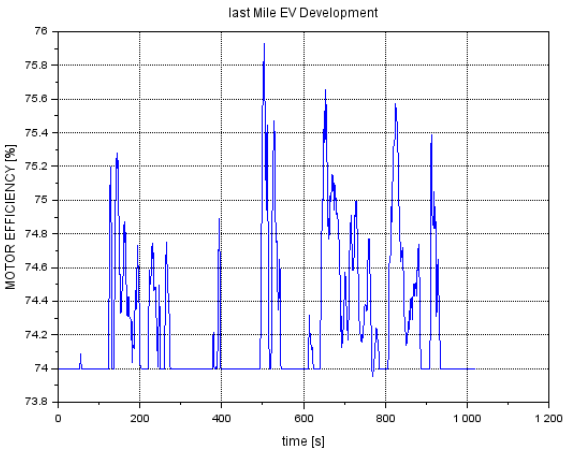

Figure 16: Motor Efficiency

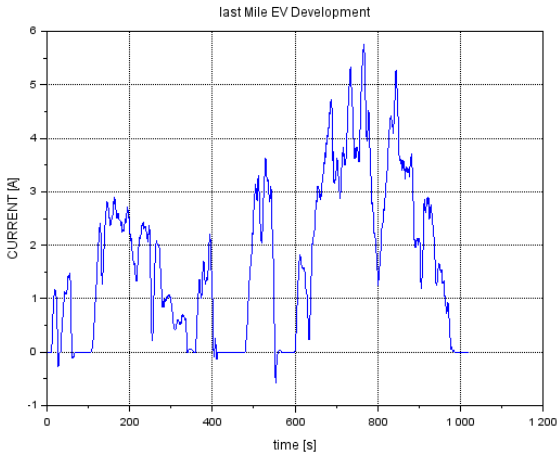

Figure 17: Battery Pack Current

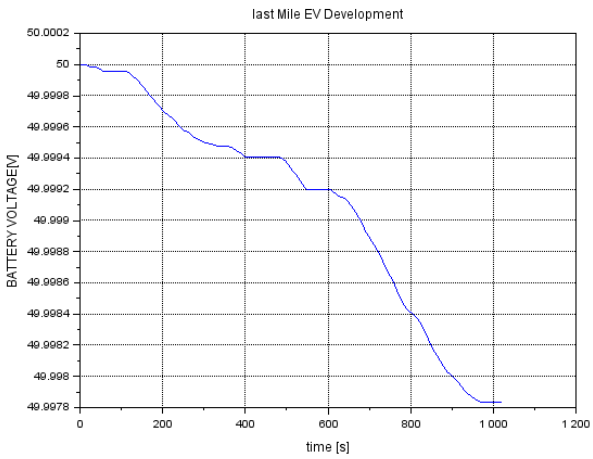

Figure 18: Battery Pack Voltage

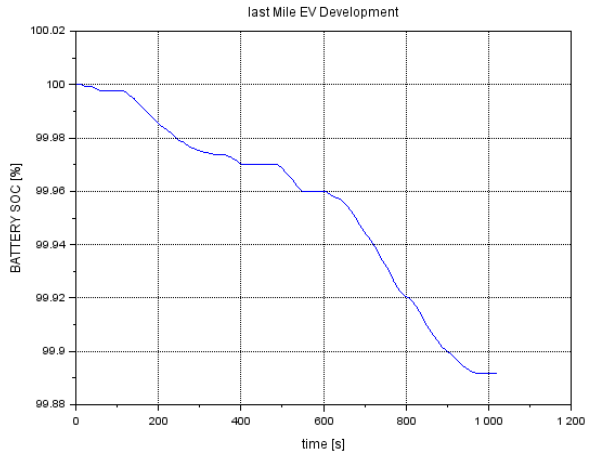

Figure 19: Battery Pack State of Charge (SOC)

VII-VEHICLE STRUCTURE OR CHASSIS DESIGN

The electric vehicle chassis is composed of the frame and almost all the subsystems we can find in a conventional vehicle chassis.

For the purpose of this work a CAD model of the vehicle is develop in SOLIDWORKS, the model is ready for prototyping and can serve as based for further development. Figure 20 showorthographic view of the vehicle.

Figure 20: Orthography view of vehicle CAD model

VIII-CONCLUSION

In this work, a last mile delivery electric vehicle is develop using model-based design software SCILAB

and a CAD model of the vehicle is design in SOLIDWORKS for prototyping purpose.

By completing this work, we can say that model-based design is a great way to develop automotive products, with this method the design is simplify and the development time is reduced since each system can be break down into smaller blocks which help to understand the system thus, reducing the design complexity.

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