İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

DESIGN AND CONSTRUCTION OF ELECTRIC MINIBUS

M.Sc. Thesis by
Ahmet APAK

Department : **Institute of Science and Technology**

Programme : **Mechatronics Engineering**

Thesis Supervisors: **Prof. Dr. Ata MUGAN**
Prof. Dr. Metin GOKASAN

JULY, 2011

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M.Sc. Thesis by
Ahmet APAK
(518091033)

Date of submission : 06 May 2011
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Supervisor (Chairman) : Prof. Dr. Ata MUGAN
Members of the Examining Committee : Prof. Dr. Metin GOKASAN
Asst. Prof. Dr.Pınar BOYRAZ
Asst. Prof. Dr.Engin YEŞİL
Asst. Prof. Dr.Ali Fuat ERGENÇ

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Ahmet APAK
(518091033)

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Tez Danışmanı : Prof. Dr. Ata MUGAN (İTÜ)
Prof. Dr. Metin GOKASAN (İTÜ)
Diğer Jüri Üyeleri : Asst. Prof.Dr. Pınar BOYRAZ (İTÜ)
Asst. Prof. Dr. Engin YEŞİL (İTÜ)
Asst. Prof. Dr. Ali Fuat ERGENÇ (İTÜ)

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FOREWORD

I would like to express my deep appreciation and thanks for my advisors & project friends. ITU Institute of Science and Technology, State Planning Office (DPT), Karsan A.S., A-Z Tech Ltd. & Hayyen Enterprise supports this work. I also express my appreciation to them.

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Ahmet APAK

(Mechatronic Engineering)

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ABBREVIATIONS

BMS	: Battery Management System
EM	: Electric Motor
EV	: Electric Vehicle
ICE	: Internal Combustion Engine
PMBLDC	: Permanent Magnet Brushless Direct Current
USA	: United State of America
AC	: Alternative Current
DC	: Direct Current
Te	: Engine Torque
we	: Rotational speed of em
Reff	: Effective radius of tire(r_dyn)
Rstat	: Static radius of tire
Frr	: Rolling Resistance Force(Fu)
fR	: Rolling Resistance Factor
Cd	: Drag Coefficient
Af	: Frontal Area of Minibus
Q	: air density
λ	: rotational mass factor
TR	: Moment of Wheel Rotation
e	: Error of Center Change of Wheel
m	: Vehicle Mass
Q	: Gradient
Pd	: Dynamic Pressure
V_{flow}	: Flow Speed
F_1	: Fuse Soft Start
Y_1	: Contactor Soft Start
R_1	: 270 ohm Resistance on Soft Start
F2	: Fuse Main Start
Y2	: Contactor Main Start
UQM	: Electric Motor Mark
Kb	: Kilo Byte
Sec.	: Second
CAN	: Control Area Network
Rpm	: Revolution Per Minute
ADC	:Analogue Digital Converter
DAC	: Digital Analogue Converter
DAQ	: Digital Signal System
DSP	: Digital Signal Processor
DO	: Digital Output
g	: Gravity
V,v1,v2	: Vehicle Speed variables

NVH	: Noise Vibration Harness
τ_{xx}	: Torque in x direction
I_{xx}	: Moment of Inertia in X direction
α_{xx}	: angular acceleration
a_x	: acceleration in x direction
μ	: Friction Factor
θ	: Inclination Angle
Finclination	: Inclination Force
Faero	: Aerodynamic Force
Ptotal	: Total Power
Ftotal	: Total Force
DR	: Differential Ratio
DR_used	: Differential Ratio used
Tstop	: Vehicle Stopping time
D_stop	: Stopping Distance
K	: Steering Gradient
h_cog	: height of center of gravity
a	: ratio of negative acceleration to gravitational acceleration
z	: breaking ratio
ha	: height of drag force effect level on vehicle to ground
W	: weight of vehicle on c.o.g
Fd	: drag force
h	: height of c.o.g to ground
hh	: height of trailer contact point on minibus
Rxf	: Rolling resistance friction on front
Rxr	: Rolling Resistance Friction on rear
Fxf	: Force on contact area of wheel due to vehicle on front
Fxr	: Force on contact area of wheel due to vehicle on rear
Rhz	: Perpendicular Force to the surface on trailer contact point
Rhx	: Horizontal Force to the surface on trailer contact point
L	: Distance between axles
Lo	: Distance between front axle and c.o.g
La	: Distance between rear axle and c.o.g
Wf	: Weight on Front axle
Wa	: Weight on Rear Axle
Fu	: Environmental Force
R	: Radius of Wheel
Jf	: Front axle Inertia
Ja	: Rear Axle Inertia
Fz	: Force on vehicle at z-direction
Af	: Frontal Area of vehicle
Tmax	: max. torque
Te	: Engine Torque
Dx	: Lineer Deceleration
$tv\text{-}tr\text{-}t_{(1,2,3)}$	: Time dependent variables for breaking

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DESIGN AND CONSTRUCTION OF AN ELECTRIC MINIBUS

SUMMARY

Electric minibus is planned as a shuttle on Istanbul Technical University, which is presented in this Master of Science thesis and its stages, includes not only scientific but also application stages. This electric minibus is powered by an electric motor and there is no gearbox as power train equipment. The selection steps of electric motor, battery and power electronic units are explained in details. The electric vehicle design parameters are shown with the structural diagrams. Moreover, vehicle control specifications including communication protocol, motor controller and vehicle main controller are given. Energy consumption and performance of selected components are evaluated. Following, the first prototype electric minibus is constructed and tested on university campus. Designed Control process is tested on the vehicle to improve safety and efficiency.

Keywords: electric minibus, vehicle control, vehicle efficiency, communication protocol

ELEKTRİKLİ MİNİBÜS DİZAYN VE ÜRETİMİ

ÖZET

İstanbul Teknik Universitesi kampüsü içinde ring aracı olarak kullanılması amaçlanan full elektrikli minibus aracın dizayn ve yapım asamasındaki basamakları bu yüksek lisans tezinde aktarılmıştır. Batarya ve elektrik motoru ile güç aktarımı sağlanan elektrikli minibüste, aktarma organı olarak şanzıman kullanılmamış, sadece difransiyel aradaki mekanik güç aktarımını sağlamıstır. Elektrik Motoru, Batarya ve güç yönetim sistemlerinin secim kriterleri detayları ile sunulmuştur. Önemli dizayn parametreleri yapısal diagramlar ile aktarılmıştır. Bunun yanı sıra, arac kontrolu ve arac kontrolunu saglayan haberlesme protokolunun uygulamasal olarak araca uygulanısı anlatılmıstır. Enerji tüketimi, maliyet hesaplamaları ve seçilen araç ekipmanlarının performansları detaylı olarak incelenmiştir. Araç üstünde koşturulan kontrol algoritması güvenlik ve verimlilik açısından kampüs içinde yapılan testler ile geliştirilmiştir.

Anahtar Kelimeler: Elektrikli Minibüs, Araç Kontrolü, Haberleşme Protokolü.

1. INTRODUCTION

Increasing effect of global warming, rising air pollution and having limitations on oils sources causes to find alternatives to the internal combustion engine powered vehicles. The uses energy on electric vehicle to power the vehicle is cleaner than the internal combustion engine vehicles about 97 percentage. 20 percentage of chemical energy in gasoline is used to drive a vehicle having an internal combustion engine, when 75 percentage of energy is converted to move the electric vehicle. [1] In this project, serially connected 100 cells of battery, which are lithium iron phosphate, is used to drive permanent magnet brushless direct current electric motor between the ranges of 320 to 420 volt. In this full electric minibus, there is no power train module as a transmission mechanism but the differential is used for the transmission process. The main processor of vehicle control is Microautobox d-space, which is connected to gas and brake pedals, electric motor drive unit, battery and its management system, forward and backward buttons. A control algorithm monitors electric motor torque, speed signals, temperature of each battery cells, remaining battery capacity, current and voltage supplied to electric motor. The design specifications are as follows: total weight of the minibus is about 3500 kg including 600 kg batteries and maximum capacity of minibus weight is 4500 kg with passengers and luggage. The maximum available speed is 150 km/h and travelling range is minimum 120 km at maximum load and cruising a predefined route on ITU Maslak Campus. The acceleration of vehicle is limited by controller software. In Maslak Campus, 72 km/h speed is reached in 11 seconds on 150 meter way.

1.1 Purpose of the Thesis

The aim of this project is to design and construct a full electric minibus, which will run as a shuttle on the main campus of Istanbul Technical University and uses electric. This electric minibus is designed and constructed to improve Mechatronic research in automotive industry by graduate and undergraduate students in Mechatronic Research Center.

1.2 Background

The electric vehicle is an electrically powered land vehicle was produced in 1834 before the invention of internal combustion engine. The electric vehicles are used in the rural areas until Mid-1910s. The rare electrification of rural areas and cheap oil prices causes using the internal combustion engine vehicles. [1]

The vehicle history about the fuels can be summarized in three groups. These are vehicle working with steam, electric vehicles and internal combustion engine vehicles. There can be also cascade structures like hybrid vehicles, which define the interrelationship between them during three stages of vehicle history. Figure 1.1 shows the steam has been passed by as a vehicle source but the electric vehicles are used generally in rural areas. The petroleum-based fuels are expensive so the electric vehicles are used in rural areas in 1834s. After oil discovery and its separation in the world in 1859s, and the electrification problems at this century, the internal combustion engine vehicles become valuable than the electric vehicles.

The electric vehicles are used as a commercial product in the third century. [2] Today, all vehicle companies in the world have been working on electrical or hybrid vehicles about their research and development.

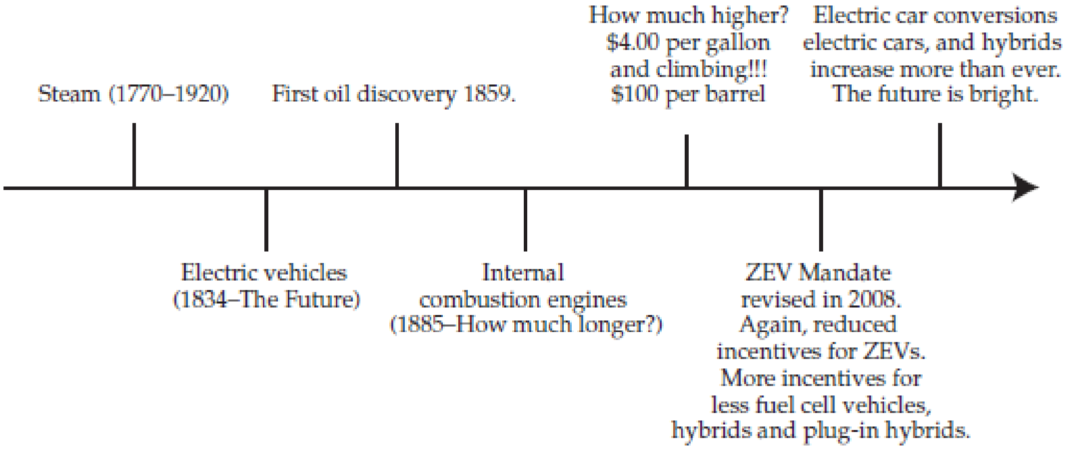


Figure 1.1 : History of Electric Vehicles.

1.3 Hypothesis

This study provided an opportunity to look at forecast issue with a wide range of information technically. This Master of Science thesis emphasizes the widely held opinion in scientific area, which is university research. In the near future, the uses of the electric vehicles will be more than internal combustion engine vehicles. In the chart in Figure 1.2[1], the gasoline vehicle line is relocated with electric vehicle line, which means the alternative energy sources will be used effectively so the energy consumption will be clean and healthy. Figure 1.2 is the chart for USA but it is parallel to the world's situation and the chart lines electric and gasoline will be relocated and changed with each other at the beginning of 2020s.

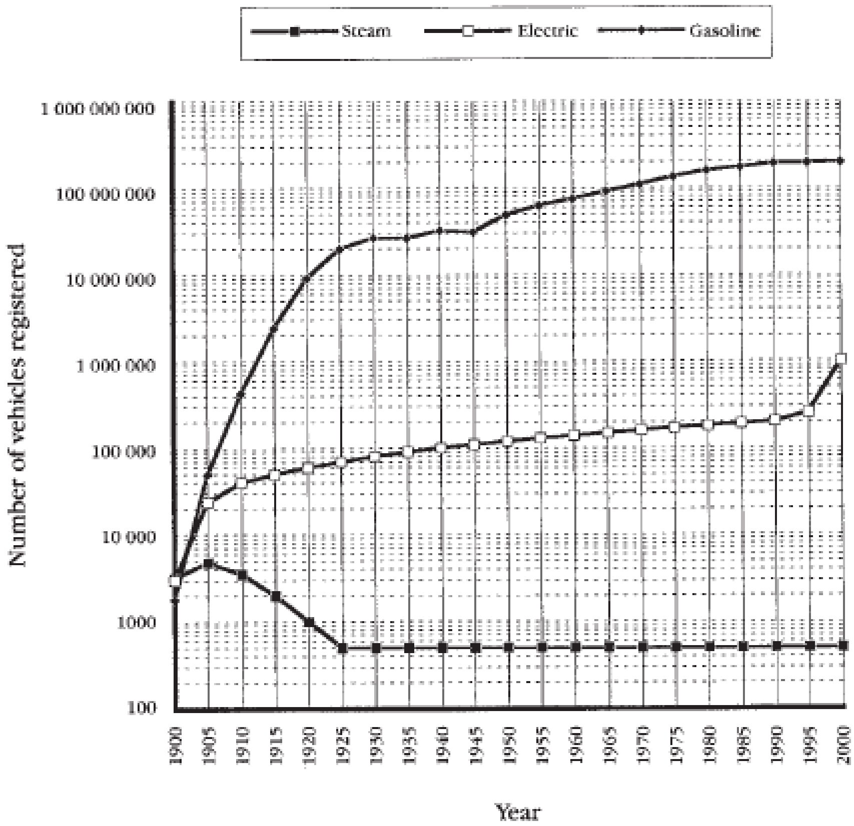


Figure 1.2 : Growth of the three vehicle types from 1900 to 2000 in USA.

2. VEHICLE DYNAMICS OF ELECTRIC MINIBUS

2.1 Vehicle Dynamic Parameters

The vehicle dynamics include the all vehicle parameters due to lots of vehicle types such as road vehicles, sea transport vehicles, airway vehicles. In this part, the parameters are associated with road vehicles. These parameters includes mechanical terms, electronic terms, solid matter terms and control terms. The vehicle parameters are investigated in five parts. The parts explain aerodynamic parameters, geometric parameters, parameters about mass, dynamical parameters and wheel parameters. The Figure 2.1 shows them in details.

Dynamical Parameters	**Geometrical Parameters**
Load Transfer Critical Speed NVH Over steering Under steering Body Wheel Angles	Ackerman Geometry Axle Geometry Camber Angle Caster Angle Wheel Height Toe Angle Shaft Distance
Aerodynamic Parameters	**Parameters Of Mass**
Vehicle Friction Factor Vehicle Aerodynamic Center of Pressure Ground Effect Down forces	Center of Mass Moment of Inertia Center of Roll Spring-Upspring Mass Mass Distribution
Wheel Parameters	
Load of Camber Circle of Steering (Road) Curve Force Ground Pressure	Rolling Resistance Force Slip Angle Load Sensitivity

Figure 2.1: Ground Vehicle Parameters.

2.2 Vehicle Dynamic's Law

The vehicle dynamics calculations for road vehicles are based on the Newton's Second Law. The formula shows the mass and acceleration relationship to enable the force that the system has.

The vehicle system, which has longitudinal direction, includes the vehicle dynamic formula as below:

$$\sum F_x = m * a_x \qquad \textbf{(2.1)}$$

Fx is the total forces in x direction, m is the mass of vehicle and a_x is the acceleration in x direction.

The rotational systems include the Newton's Formula as below:

$$\tau_{xx} = I_{xx} * \alpha_{xx} \qquad \textbf{(2.2)}$$

τ_{xx} is the torque in x direction, I_{xx} is the moment of inertia in x direction and α_{xx} is the angular acceleration.

Vehicle mass is investigated in these calculations for empty vehicle and for full vehicle with the passengers and luggage's. Moreover, the lateral forces affect longitudinal acceleration and they are emphasized in calculations.

Rotational systems such as tires are evaluated with the properties and charts and they are explained with the measurements in this section 2. These systems are investigated not only with power terms but also with dynamical terms.

The limits and restrictions are mainly emphasized in vehicle dynamic calculations. They enable to understand how the electric minibus can travel. These limits also affect the vehicle design directly.

Vehicle Dynamic calculations in Section 2 in this thesis, enables to show restrictions and limits which are exhibited in Table 2.1. The electric minibus can travel with these limits. The speed, which is 30 km/h, is thought as the nominal speed of electric minibus in the Maslak Itü Campus in Turkey.

Table 2.1: Vehicle Dynamic Limits

Limit Factor	Symbol	Value	Unit
Rolling Resistance Factor	f_R	0.013825	-
Max. Rolling Resistance Force@75 km/h	F_{RR}	571	Newton
Statistical Friction Factor @ max. Speed	μ	0,7	-
Dynamic Radius for Electric Minibus	r_{eff}	0,35	meter
Max. Gradient for The Campus	q	15	%
Max. Inclination Angle	θ	8,53	Degree
Max. Inclination Force	$F_{inclination}$	6547,9	Newton
Drag Coefficient for Electric Minibus	Cd	0,4	-
Aerodynamic Force	F_{aero}	510,86	Newton
Max. Total Resistance Power	P_{total}	110,653	kw
Max. Total Resistance Force	F_{total}	2655,67	Newton
Min. Differential Ratio	DR	4,11	-
Used Differential Ratio	DR_used	5,28	-
Stopping Time @ 30 km/h	t_{stop}	1,65	second
Stopping Distance @ 30 km/h	D_{stop}	12--14	meter
Ackerman Angle @ 100 meter curve radius	δ	1,89	degree
Steering Of Minibus	-	Neutral	-
Understeering Gradient	K	0	-
Height Of Center Of Gravity Range	h_{cog}	75-100	cm
Acceleration Limit	a	0,8g< a< 1.1 g	-

Thanks to these limits, the vehicle components can be chosen such as electric motor, steering wheels, positions of the vehicle parts at the interior body, breaking performance etc…

2.2.1 Dynamical Forces on Vehicle

The basic rule of Newton's Second Law is to use the force components on the axes. The Figure 2.2 shows the forces, which affects the vehicle directly.

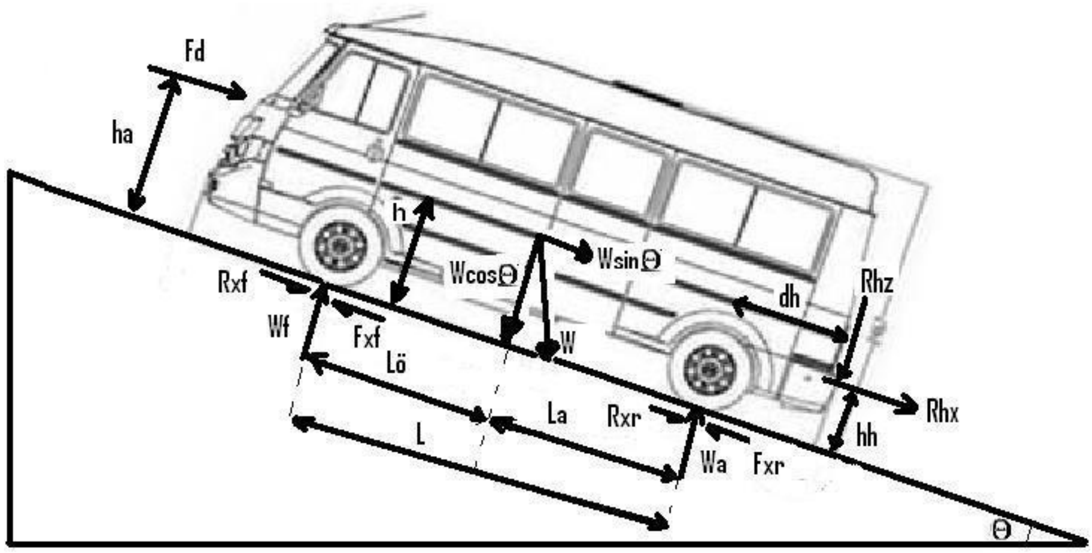


Figure 2.2: Forces on Electric Minibus.

In Figure 2.2, "W" is the weight which effect the vehicle on center of mass. The "g" is the gravity term. Moreover, "Wf" and "Wa" are dynamical forces, which affect the wheels that are perpendicular to the wheel surfaces. Fxf, Fxr are the forces that affect the contact area between surface and wheels. Rxf, Rxr are the rolling resistance frictions. Next,"Fd" is the aerodynamic force effects to the vehicle speed. If there is a trailer, the terms "Rhz" and "Rhx" are perpendicular and horizontal forces that also affect the vehicle. L is the length between front and back axles. When "La" is the distance between rear axle and center of mass, "Lo" is distance between front axle and center of mass and vice versa.

If the vehicle speed is constant, these terms have a relation as the formula below:

$$(W_f*L)+(F_d*h_a)+((W/g)*ax*h)+(R_{hx}*h_h)+(Rhz*dh)+(W*h*\sin\theta)-(W*La*\cos\theta)=0 \quad \textbf{(2.3)}$$

2.3 Acceleration Performance of Electric Vehicle

The acceleration performance of the vehicle is limited by two parameters. These are:

1-Power-Limited Acceleration Performance

2- Traction-Limited Acceleration Performance.

When the vehicle speed is high, electric motor power is the case to limit the performance. On the other hand, friction between wheels and the ground describes traction limit when the electric motor power is enough for the instantaneous situation. The power-limited acceleration performance analyses the motor characteristics and relationship between electric motor and power train equipments. Power calculation of electric vehicle is explained in Section 2.4 and Motor Characteristics are investigated in Section 3, which explains all electric motor information.[6]

The traction-limited performance is based on maximum friction factor (μ), Rxf, and Rxr. "Rxf "and "Rxr" are the forces on the wheels due to the friction. The traction force (Fx) is composed by these terms.

$Fx = \mu * R$ **(2.4)**

$Fxf = \mu * Rxf$ (for the front wheels) **(2.5)**

$Fxr = \mu * Rxr$ (for the rear wheels) **(2.6)**

Fx is proportional to load on wheels.

2.4 Electrical Power Calculations

There are four main factors, which avert the movement of vehicle when it travels along the road. These are:

2.4.1 Rolling Resistance Force
2.4.2 Inclination Force
2.4.3 Aerodynamic Force
2.4.4 Acceleration Force
2.4.5 Total Resistance Force

Total force of them is multiplied with the vehicle speed so that understanding of required power what the vehicle needs. [6]

2.4.1 Rolling Resistance Force

When the vehicle is on the ground, load on the vehicle causes the tires smash the ground and the ground smashes the tire surface, which contacts the ground. That is to say, when the tire is going on, the moment is produced which should be bigger than the rolling resistance.

The rolling resistance is the factor that wants to avoid the tire propulsion. This comes from the contact between pneumatic tire and ground, which causes the cavity due to the load. The rolling resistance changes with factors such as applied load, application conditions and the production factors.

The rolling resistance causes the additional power to move the tires. This additional power is compensated with the additional energy production so, there is a direct relation between the rolling resistance and the necessary energy to move the vehicle. [6]

The rolling resistance forces & the moments are shown in Figure 2.3.

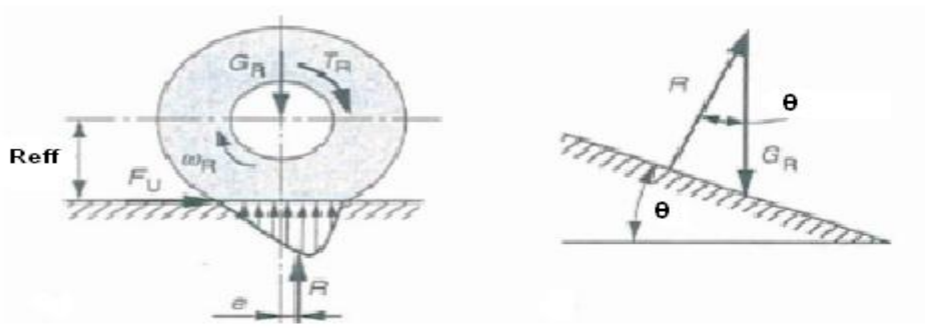


Figure 2.3: Acting Forces and Moments on Tire.

The "T_R" is the moment of wheel rotation and it is formulated as:[6]

$$T_R = F_u * R_{eff} + R * e \quad \textbf{(2.7)}$$

In formula **(2.7)**, "Fu" is environmental force and it is thought as the same as rolling resistance force; effective radius (R_{eff}) of tire is the dynamic radius, which is not static so the load is applied to tire. R is the static radius, which is the radius without any load on tire. "e" is the error of the center change on tire before and after the load.

If the tire rotates without break moment, environmental force is equal to rolling resistance force, the formula can be defined as:

$F_{RR} = (e/R_{eff})*m_{wheel}*g$ **(2.8)**

The ratio of (e/R_{eff}) is the rolling resistance factor which is called as "f_R". This factor is different from surface to surface. The different values of f_R is shown in Table 2.2.

Table 2.2: Surface-Rolling Resistance Factor Relation

Road Surface	Rolling Resistance Factor, fR
Flat asphalt	0.01
Flat Concrete	0.011
Hilly Good Concrete	0.014
Good Stone	0.02
Bad Tired Off	0.035

According to experiments, the rolling resistance is formulated and this formulation can be changed by experiment to experiment. For example, Figure 2.4 shows one of the experiments data chart and the related formulas are also given. [6]

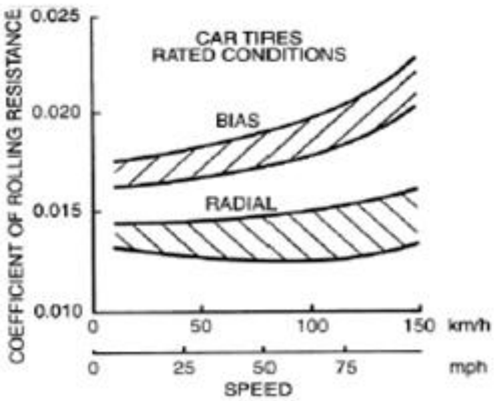


Figure 2.4: Rolling Resistance & Speed Graph.

The related rolling resistance factor formula for this experiment is;

f_R= 0, 0136 + 0, 4 * 10^ (-7) * V^ (2) **(2.9)**

f_R= 0, 0136 + 0, 4 * 10^ (-7) * 75^ (2) **(2.10)**

f_R= 0,013825 **(2.11)**

The rolling resistance value is near to value of Hilly Good Concrete in Table-2.2.

$F_{RR}= f_R*m*g$ **(2.12)**

F_{RR} =(0,013825)*(4500)*(9,18) **(2.13)**

F_{RR} = 570,078 N(Rolling Resistance Force) **(2.14)**

Taking everything into consideration, rolling resistance of the electric minibus can take the highest value if the value of f_R can be maximum with the highest value of vehicle speed. For the electric minibus, the maximum vehicle speed is thought as 75 km/h which is 20, 8 m/sec. When the speed is 20, 8 m/sec, f_R value is 0, 0138. So the F_{RR} is 570, 078 Newton. It is 0, 57 kN.

2.4.1.1 Selection of Effective Radius of Wheels & Adhesion Effect

There is a relationship between the wheels and surface of ground. The environmental forces Fu is proportional to loads, which are carried by wheels.

$F_{u\_max} = F_{z\_max} = \mu * R$ **(2.15)**

Fz, which is the tractive effort between wheel and surface of ground, is limited by adhesion. Adhesion is a limitation, which is the relationship between maximum load that the wheel carries and the vehicle speed. Adhesion limit shows the maximum load capacity of wheels to carry.[6]

The Figure 2.5 shows the secondary map of vehicle, which does not have a gearbox like electric minibus.

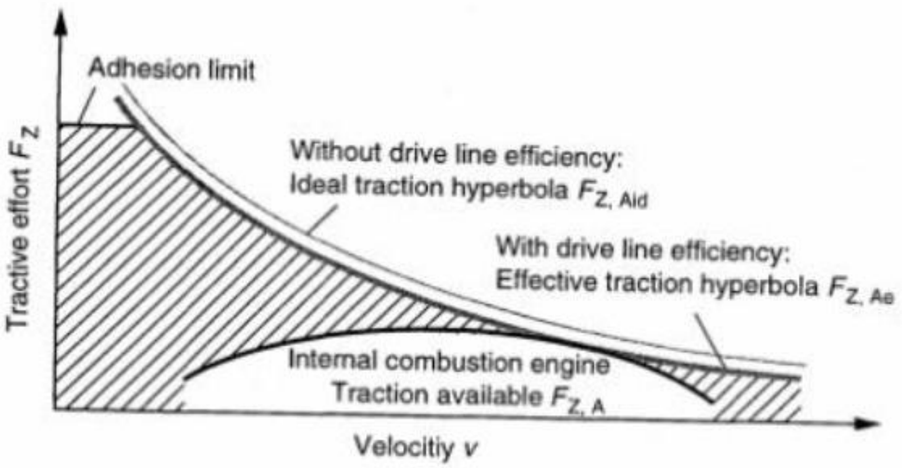


Figure 2.5: 2nd Map of Vehicle without Gearbox.

μ is the statistical friction factor and its value changes with two factors. These are:

-Vehicle Speed

-Surface Type of Ground

The table 2.2 shows the friction factors for different speeds.

Table 2.3: Speed & Friction Factor Values

Vehicle Speed	Statistical Friction Factor "µ"	
Km/h	Dry Surface	Wet Surface
50	0.85	0.65
90	0.80	0.60
130	0.75	0.55
170	0.70	0.50

Static radius is not consequential tyre radius due to movement of vehicle so the effective radius of wheels is investigated. The vehicle effective radius types are shown in Table 2.3 and the electric minibus effective radius is 0.35 meter as dynamic.[6]

Table 2.4: Effective Radius Chart

WHEEL TYPE NUMBER	ROLLING CIRCUMSTANCE	r_{dyn} (m)	WHEEL TYPE NUMBER	ROLLING CIRCUMSTANCE	r_{dyn} (m)
	PASSANGER TRANSPORT			PASSANGER TRANSPORT	
135 R 13	1.670	0.266	205/65 R15	1.975	0.314
145 R 13	1.725	0.275	195/60 R15	1.875	0.298
155 R 13	1.765	0.281	205/60 R15	1.910	0.304
145/70 R13	1.640	0.261		LIGHT COMMERCIAL VEHICLE	
155/70 R13	1.680	0.267	185 R 14	1.985	0.316
165/70 R13	1.730	0.275	215 R 14	2.100	0.334
175/70 R13	1.770	0.282	205 R 14	2.037	0.324
175 R 14	1.935	0.308	195/75 R16	2.152	0.343
185 R 14	1.985	0.316	**205/75 R16**	**2.200**	**0.350**
195/70 R14	1.940	0.309		LORRY AND BUSES	
185/65 R14	1.820	0.290	12 R 22.5	3.302	0.526
185/60 R14	1.765	0.281	315/80 R 22.5	3.295	0.524
195/60 R14	1.800	0.286	295/80 R 22.5	3.215	0.512
195/70 R15	2.000	0.318	215/75 R 17.5	2.376	0.378
185/65 R15	1.895	0.302	275/70 R 22.5	2.950	0.470
195/65 R15	1.935	0.308	305/70 R 19.5	2.805	0.446

2.4.2 Inclination Force

The inclination is the positive or negative resistance to the vehicle. While the vehicle goes down, this resistance is positive. It is negative when the vehicle goes up. The Figure 2.6 shows the electric minibus is on the inclination.

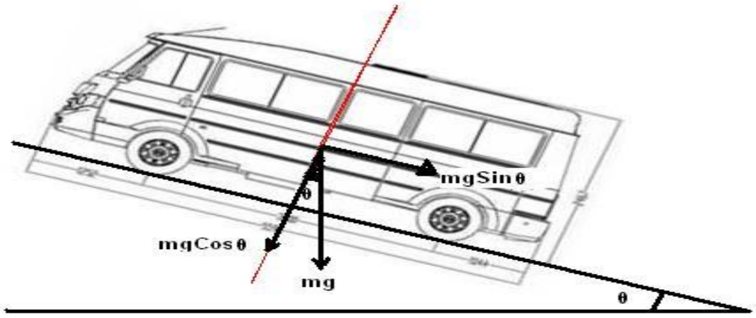


Figure 2.6: Loads on Center Of Mass.

As it is shown in Figure 2.6, the vehicle mass is described, as perpendicular to ground and it is not perpendicular to slope surface. This perpendicular vector has two components which are [m*g*Cos θ] and [m*g*Sin θ]. The "m*g*Cos θ" is the load which is the affect of vehicle mass on the slope surface. There is a force on the vehicle tires, which has the same direction with the electric minibus. This force protect vehicle from rolling down. Because of this force, the "m*g*Sin θ" is applied opposite to it. [5]

The inclination force is one of the components of vehicle mass and this force is decided with the slope of the inclination.

$$F_{inclination} = m*g* \sin \theta \quad \textbf{(2.16)}$$

The horizontal projection of inclination has a ratio with vertical projection. Horizontal one divides the vertical one, the ratio is defined as gradient, and its symbol is q. In the world, this gradient changes between 5 % and 26 %. It is normally preferred as maximum value about 6-8 %.

In Electric Minibus Calculation, the maximum slope is 15 %. This percentage comes from the maximum slope on the map of Istanbul Technical University.(see Appendix-6)

$q = \tan\theta$ **(2.17)**

Gradient, which is tan θ, is generally equal to sin θ.

$(0, 15) = \tan(\theta)$ **(2.18)**

$\theta = 8, 53$ (inclination angle=gradient) **(2.19)**

With this gradient, Formula 2.9 is rearranged which is formula 2.13.

$F_{inclination} = m*g*\text{Sin}(8{,}53)$ **(2.20)**

$F_{inclination} = 4500\ \text{kg} * 9{,}81\ \text{kgm/sec}^{\wedge}2 * (0{,}148)$ **(2.21)**

$F_{inclination} = 6547{,}9$ Newton **(2.22)**

In the electric minibus application, the maximum percentage is 15 %, so the force "$F_{inclination}$" is maximum as 6, 5 kN. The 15 % slope is the same meaning as "tan(8,53)" degree.

2.4.3 Aerodynamic Force

The air resistance is one of the main forces that cause drag on the minibus. In addition to it, lateral and lift forces are the other important forces affect the vehicle. [6] The airflow around the vehicle is an important factor for the vehicle stability and energy consumption. The air resistance on the minibus includes pressure owing to drag resistance, surface resistance and resistance into flow. The air resistance is the second order function of flow speed. The flow speed is resultant of vehicle speed component and wind speed component as shown in Figure 2.7

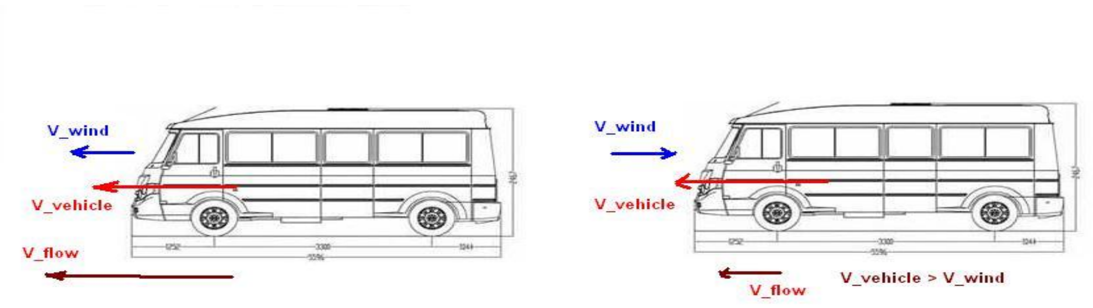


Figure 2.7: Speed Configuration.

In addition to them, if the direction of wind speed is at the same direction with the vehicle, the summation of vehicle speed and wind speed will be thought as flow speed. If the direction of wind speed is opposite of vehicle speed, the flow speed is difference of vehicle speed to wind speed.

The dynamical pressure formula about the subject is:

$P_d = (½) * \rho * (V\_flow^2)$ **(2.23)**

In formula (2.6), the speed (V_flow) is the flow speed, density (ρ) is the air density.

The minibus frontal area (A_F) is 4, 8 m^2 as shown in Figure 2.8. The height is without vehicle load, which is 2,467 meter, and the width is 1, 94 meter. The frontal area is the multiplication of them.

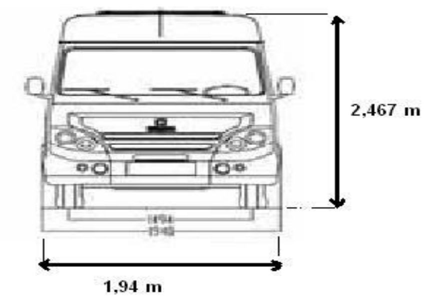


Figure 2.8: Width and Height of Vehicle.

The other important factor for air resistance is drag coefficient “C_d”. Fluids such as water, air cause the resistance to the objects and matters. The value of this resistance is proportional to flow shape, frontal area of object, and square of flow speed.

Generally, there is an acceptance that flow is flat and the wind speed has the same direction with vehicle speed. Table-2.5 shows the drag coefficient values according to vehicle types.

Table 2.5: C_d & Vehicle Relation

Vehicle	Cd (Drag Coefficient) Range
Motorcycle	0.5-0.7
Cars	0.2-0.4
Van-Minibus-Bus	0.4-0.8
Lorry	0.5-1.0
Articulated Vehicle	0.5-0.9

Motorcycles have bigger drag than cars, and the biggest one is the lorry drag. This range can be explained with the vehicle figures to understand it better in Figure 2.9.

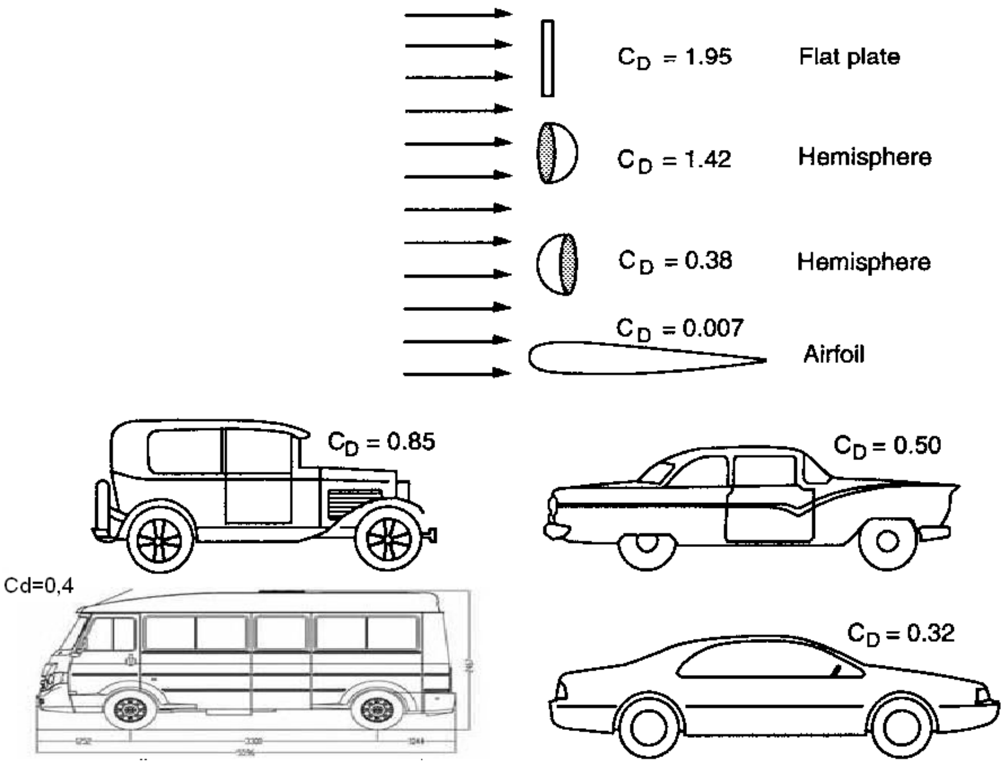


Figure 2.9: Drag Coefficient Values with Vehicle Figures.

As it is shown in Figure 2.9, the drag coefficient values change by vehicle to vehicle. When one car (@ Top &Right in Figure 2.9) has the drag coefficient of 0, 5, the other one (@ Bottom & Right in Figure 2.9) has 0, 32 and vice versa. It comes from the aerodynamic structure difference. [6] The minibus has the drag coefficient of 0.4. Taking everything into consideration, dynamical pressure (Pd) formula will be related with drag coefficient and vehicle speed so that to find the new force which is air resistance force and it can be described with the formula below:

F_{aero} = (1/2)* ρ * C_d * A_F *(V^2) **(2.24)**

F_{aero} = (1/2)* (1,23) kg/m^3 * (0,4) * (4,8) m^2 *(20,8^2) m^2/sec^2 **(2.25)**

F_{aero} = 510,86 Newton **(2.26)**

In the electric minibus application for the 75 km/h speed, the air resistance force is 510,86 Newton called as 0,5 kN.

2.4.4 Acceleration Force

If the driver steps on the gas when the vehicle starts to move, the vehicle is accelerated. The way and the environmental conditions cause a resistance opposite to this acceleration with the same value, this force is called acceleration force. The positive traction forces are used for acceleration. This force is transmitted from driveline to drive wheels and it is the force against to wind speed, rolling resistance etc… Vehicle mass is multiplied with a factor called rotational mass factor (λ) which is caused by rotation of power transmission components. So, the acceleration force is formulated as below:

$$F_a = \lambda * m * a \qquad \textbf{(2.27)}$$

λ is rotational mass factor and described with the terms of inertia, mass and load effect to the wheels on the surface which can be thought equal for each tires. Rf=Ra=r. The formula for λ is below:

$$\lambda = 1 + ((Jf+Ja)/(m*r\string^2)) \qquad \textbf{(2.28)}$$

Ja and Jf are the inertias of front and rear parts on axes of axles.

2.4.5 Total Resistance Force

Total resistance force is composed by rolling resistance force, inclination force, air resistance force and acceleration force. The rolling resistance force and inclination force are independent from the vehicle speed. The air resistance force and acceleration force are dependent to vehicle speed. Total Resistance Force can be formulated as below:

$$F_{total} = F_{RR} + F_{inclination} + F_{aero} + F_a \qquad \textbf{(2.29)}$$

If the formula is written in details:

$$F_{total} = f_R * m * g + m * g * \sin\theta + (1/2) * \rho * C_d * A_F * (V\string^2) + \lambda * m * a \qquad \textbf{(2.30)}$$

Table 2.6: Energy Consumption Chart

fR	FRR	F_aero (N)	V (km/h)	V (m/sec)	Total Force (N)	Necessary Power (kw)
0,0136	573,69	0,00	0	0	573,69	0,000
0,013601	573,73	2,27	5	1,39	576,00	0,800
0,013604	573,86	9,08	10	2,78	582,94	1,619
0,013609	574,07	20,44	15	4,17	594,51	2,477
0,013616	574,36	36,34	20	5,56	610,70	3,393
0,013625	574,74	56,78	25	6,94	631,52	4,386
0,013636	575,21	81,76	30	8,33	656,97	5,475
0,013664	576,39	145,35	40	11,11	721,74	8,019
0,0137	577,91	227,11	50	13,89	805,02	11,181
0,013744	579,76	327,04	60	16,67	906,81	15,113
0,013796	581,96	445,14	70	19,44	1027,10	19,971
0,013856	584,49	581,41	80	22,22	1165,90	25,909
0,013924	587,36	735,84	90	25,00	1323,20	33,080
0,014	590,56	908,45	100	27,78	1499,01	41,639
0,014084	594,11	1099,22	110	30,56	1693,33	51,741
0,014176	597,99	1308,17	120	33,33	1906,15	63,538
0,014276	602,20	1535,28	130	36,11	2137,48	77,187
0,014384	606,76	1780,56	140	38,89	2387,32	92,840
0,0145	611,65	2044,01	150	41,67	2655,67	110,653

The biggest necessary power which is 110,653 kW in this chart. For this power, the maximum speed is 150 km/h and total force is 2655, 67 Newton.

2.5 Differential Ratio of Electric Minibus & Selection of Differential

To calculate the differential ratio, the maximum torque, which is used for the vehicle, and the maximum torque which the electric motor has, should be known so the half the battle limits can thought to find the differential ratio.

In section 2.4.1, the rolling resistance force for the maximum limit is found as 570,078 N (F_{RR}). In Section 2.4.2, the inclination force for the maximum limit is calculated as 6547, 9 Newton ($F_{\_inclination}$). In Section 2.4.3, the aerodynamic force is taken for the maximum limit with the calculations as 510, 86 Newton ($F_{\_aero}$). The vehicle speed can be thought as constant due to inclination. If the inclination is in the calculation, the acceleration force can be negligible. On the other hand, if the acceleration force is used, the way will be assumed as flat and there will be no inclination force.

$$F\_total = F_{RR} + F_{\_inclination} + F_{\_aero}$$

$$F\_total = 570.078\ (N) + 6547.9\ (N) + 510.86\ (N) = 7627\ Newton \qquad \textbf{(2.31)}$$

The total forces is multiplied with the tire radius to find the maximum torque.

$$T_{max.} = F\_{total} * r\_{tire} \quad \textbf{(2.32)}$$

$$T_{max} = 7627\ (N) * 0.35\ (m) \quad \textbf{(2.33)}$$

$$T_{max.} = 2669.45\ Nm \quad \textbf{(2.34)}$$

The differential ratio is found by the ratio of maximum torque to electric motor torque.

Differential Ratio (DR) = Tmax. / Te **(2.35)**

Electric motor maximum torque is 650 Nm, which is emphasized in Section 3.4.

DR= 2669.45 / 650 **(2.36)**

DR = 4.11 **(2.37)**

The differential should be chosen with the ratio bigger than 4.11. Mitsubishi Pajero 99 is used as differential in electric minibus. The maximum motor power is 147 kW when the electric motor power is 150 kW. The maximum motor torque of the differential is 441 Nm when the electric motor maximum torque is 650 Nm. Moreover, the minimum ratio limit is 4.11 when this differential has a 5.28 ratio. The diameter of the differential is 23 cm when the electric minibus has a 25 cm area for it. Taking everything into consideration, it is possible to use this differential for this application.

2.6 Breaking System Calculations

2.6.1 Breaking System Components

The breaking performance is consequential effect to stop the vehicle securely. The breaking forces are rolling resistance force, aerodynamic force and power train losses. The electric minibus has the disc breaking system and it does not include ABS system. The vehicle breaking system components are shown in Figure 2.10.

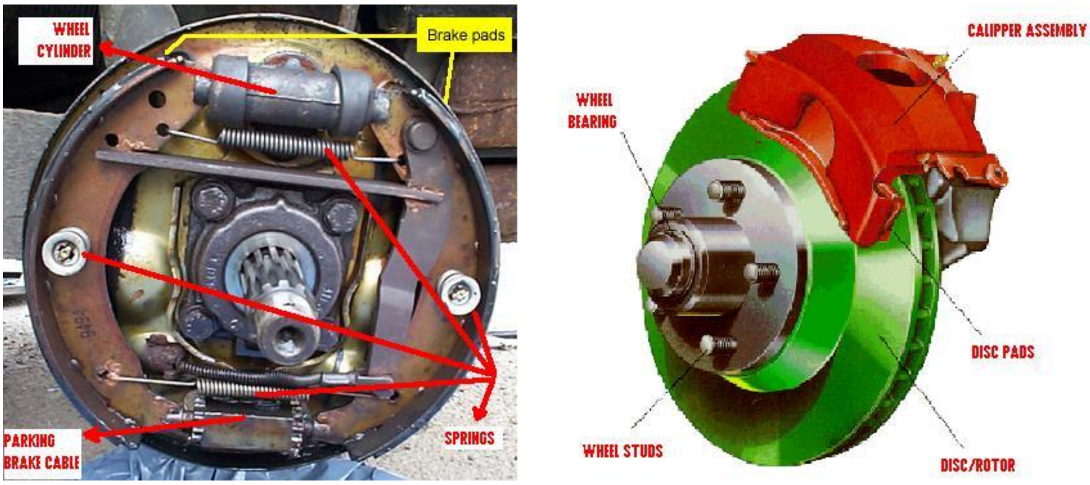


Figure 2.10: Break System Components.

The basic breaking system formula, which is formulated as the x-directional with Newton's Second Law, is below.

$$m*a_x=-(w/g)*D_x=-F_{xf}-F_{xR}-Faero -W*\sin(\theta) \qquad \textbf{(2.38)}$$

The "m" is the vehicle mass, which is stopped, w is the weight of vehicle, "g" is the gravity, ax is the acceleration on x-direction. Moreover, Dx is the lineer decelaration, Fxf and Fxr are the braking forces on the rear and front. θ is the uphill grade.

Breake pads convert the kinetic energy of the car to thermal energy by friction. The disc pads are the equipments enables stooping with caliper assembly.

2.6.2 Breaking Dynamics

The necessary power of vehicle tires can be explained with the parameters of total forces and vehicle speed. With the assumption of no slip and the equal values of static radius and effective radius, the power of tires can be described with the formula below:

$$Pw= F_{total} * V \text{ (Breaking Power)} \qquad \textbf{(2.39)}$$

The power of breaking is calculated with the same equations which is explained in the "Part 2.4.1.5" that is the total forces which affects the vehicle.

The work can be described with the formula 2.40.

$$W = \int P \, dt \text{ (work description)} \qquad \textbf{(2.40)}$$

2.6.3 Breaking Ratio

The breaking ratio is defined as the ratio of negative acceleration to gravitational acceleration. It is called as "z".

$$Z = -a / g \qquad \textbf{(2.41)}$$

Appendix-6 shows the Maslak Campus ways in which the electric minibus will be used. The maximum gradient of the path is 12 %. When the electric minibus is full with the passengers, the weight is 42813 Newton. When the average speed of minibus is 30 km/h (8,33 m/sec.) and breaking ratio is z , power and work calculations are calculated with the codes shown in Appendix-7. The breaking power and breaking heat charts with the breaking ratio are in Figure 2.11, which is calculated by the Appendix-9 codes.

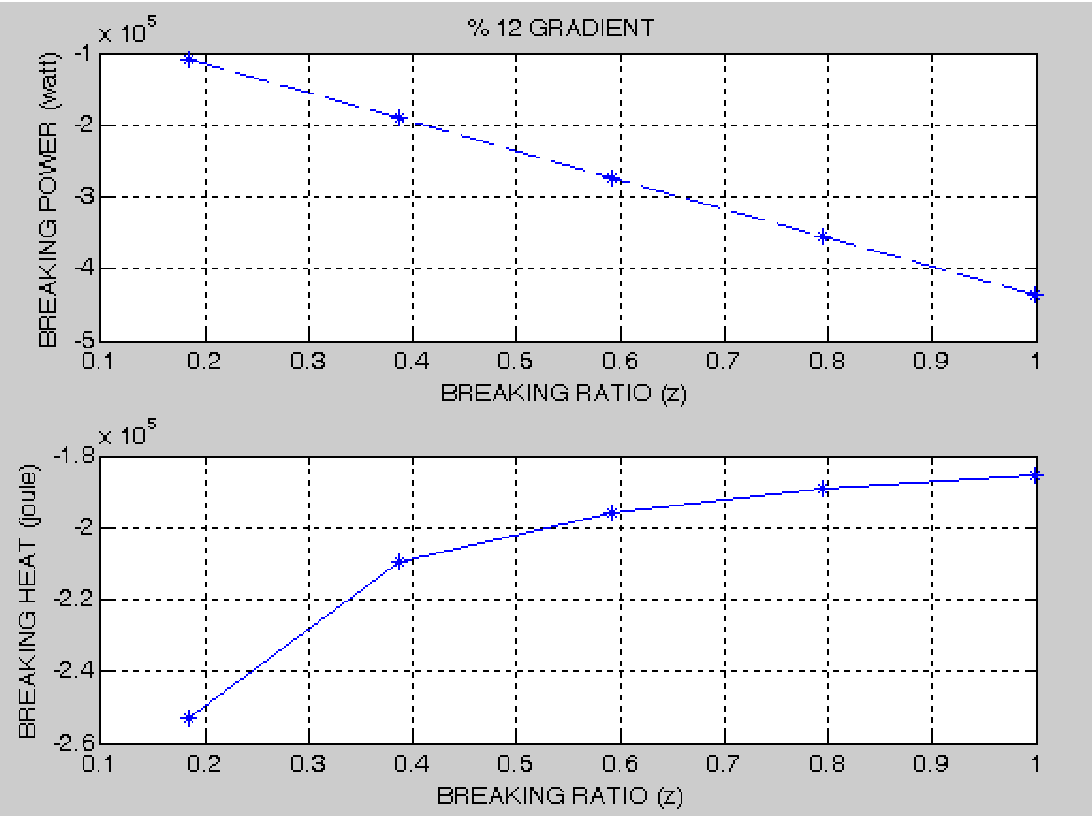


Figure 2.11: Break System Graphs @ Constant Speed .

As it is shown in Figure 2.11, breaking power is high to provide the high breaking acceleration. On the other hand, the breaking time is short so the breaking heat is low. If low breaking acceleration is needed, the breaking power is low but breaking time is short so breaking heat is high. It is emphasized in Table 2.7 which shows the breaking energy and power with respect to breaking ratio.

Table 2.7: Breaking Ratio – Energy & Power Chart

Breaking Ratio	Breaking Energy (Joule)	Breaking Power (Watt)
1	-185311,73	-436472,52
0,7961264	-189214,3	-354805,2
0,5922528	-195803,66	-273137,88
0,3883792	-209310,99	-191470,56
0,18450561	-252668,78	-109803,24

When the vehicle weight and speed are the same with the calculation of figure 2.11 and the break acceleration is constant as (-5) m/sec^2, the power and work for the campus path are explained with the codes in Appendix-8. The graph which is produced by this code is in Figure 2.12.

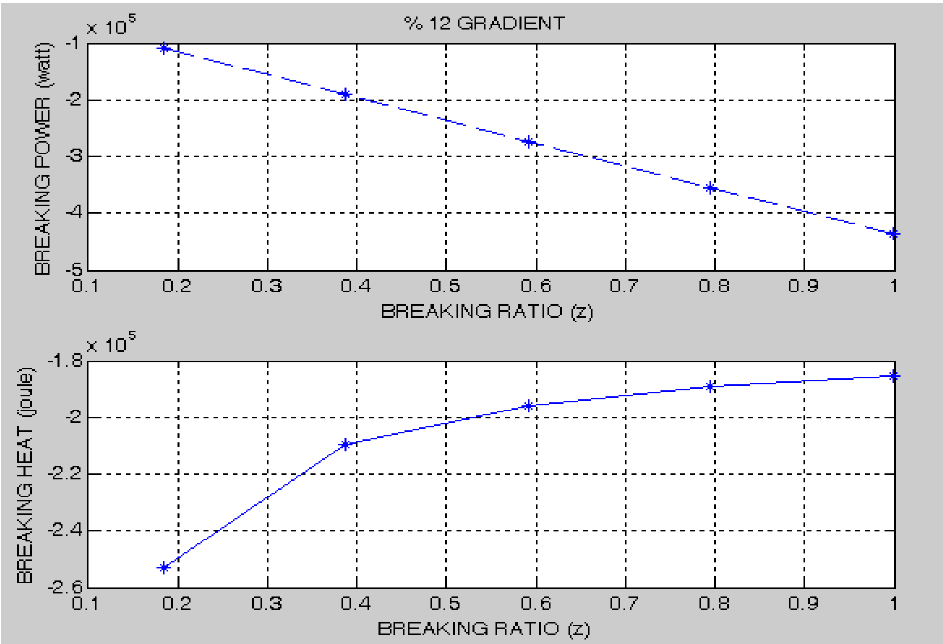


Figure 2.12: Break System Graphs @ Constant Acceleration.

It is obvious in the graph 2.12 that the relationship of gradient, breaking heat and power is about linear. The table 2.8 investigates the data relation.

Table 2.1: Breaking Ratio – Energy & Power Chart for Figure 2.12

Gradient	Energy (Joule)	Power
0	-164847,77	-197896,49
0,01	-167774,81	-201410,33
0,02	-170701,84	-204924,17
0,03	-173628,87	-208438,02
0,04	-176555,9	-211951,86
0,05	-179482,93	-215465,71
0,06	-182409,96	-218979,55
0,07	-185337	-222493,39
0,08	-188264,03	-226007,24
0,09	-191191,06	-229521,08
0,1	-194118,09	-233034,93
0,11	-197045,12	-236548,77
0,12	-199972,16	-240062,61

2.6.4 Distance of Breaking and Stopping

The breaking and stopping process takes a time period which including increase of breaking acceleration so there should be the breaking distance analyses. Figure 2.13 shows the basic breaking parameters and stopping process analyse. It explains the difference between ideal pedal and real pedal. “tr” is the time of awreness of driver about the dangerous to break the vehicle. Generally this preparation takes 0.3 to 1.7 second. The lineer increase of pedal force “tp” gets 0.1 to 0.2 second. Breaking starts for the vehicle after giving out the air space on the system and touching the brake lining to break disc.

In Figure 2.13 (b), the time between the “tr” and first breaking acceleration is called as “ta” and it can be about 0.4 second.”ts” is the time until the breaking acceleration reaches maximum and it is little bit more than the “tp” which is timing for lineer increase of pedal force. The breaking acceleration (a_v) is constant after the timing for maximum level due to constant pedal force. Moreover, “tv” is the time of breaking continues with constant acceleration.

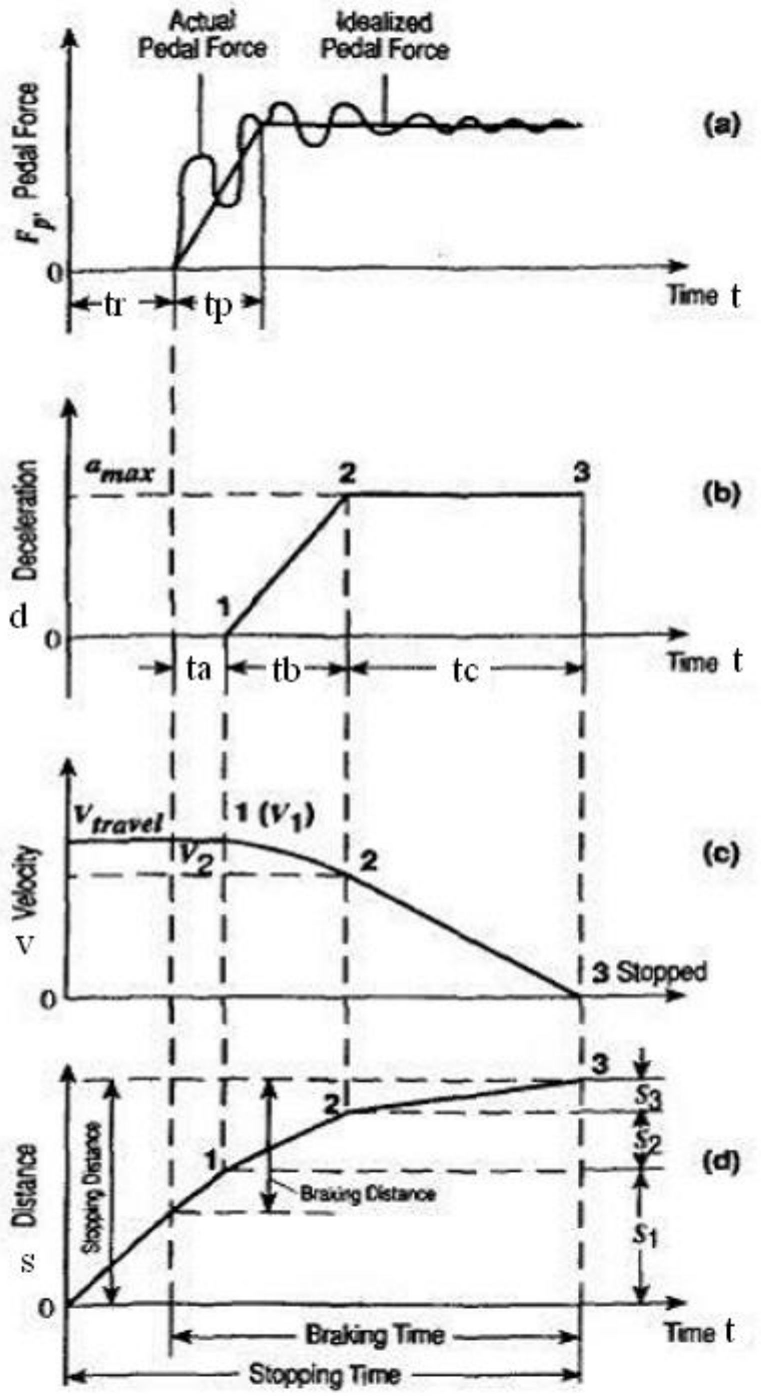


Figure 2.13: Breaking Distance Analyse.

In Figure 2.13 (c), the speed changes between point 1 and point 2 as nonlinear.Speed can be constant after the breaking acceleration is maximum. The speed change is lineer between point 2 and point 3.

Total time to stop is s1, s2 and s3 in Figure 2.13.

s1 is calculated with the parameters tr, ta and v1.v1 is the speed at the point1.

$$s1= v1*(tr + ta) \qquad \textbf{(2.42)}$$

Breaking acceleration is "a_s" at the ts time period.

$$a_s= (a_v/ts)*t \qquad \textbf{(2.43)}$$

The speed description with respect to these parameters is v and formula is below:

$$v= v1 + \int(a_v/ts)\, dt = v1+(a_v/2ts)*t\text{^}2 \qquad \textbf{(2.44)}$$

$$s2 = \int_0^{ts} v.dt = v1 * ts + \left(\frac{a_v}{6}\right) * ts\text{^}2 \qquad \textbf{(2.45)}$$

a_v is used as negative because of breaking. During the full breaking which is tv, the breaking acceleration is constant and called as "a_v". The speed change is described for "v" as below:

$$v= v2 + a_v *\int dt = v2 + a_v * t \qquad \textbf{(2.46)}$$

v2 is the speed in the formula 2.46 that is the first time point of "t_v" time period. "v" speed can be written with the combination of formulas 2.44 and 2.46. The result formula is 2.47.

$$v= v1 + (a_v / 2)* ts \qquad \textbf{(2.47)}$$

After the time period "t_v", the speed is decrease to 0. The formulas 2.46 and 2.47 are combined and the formula of "t_v" is written as formula 2.48.

$$t_v= (v2 / -a_v) = (v1 / -a_v) – (ts / 2) \qquad \textbf{(2.48)}$$

The distance which is travelling in the time periof of t_v is "s3" and it is enabled with the formula below:

$$s3 = \int_0^{tv} vdt = v2 * tv + \left(\frac{a_v}{2}\right) * tv\hat{\ }2 \qquad \textbf{(2.49)}$$

When the formula 2.49 and 2.46 combined with each other, the formula 2.50 is found.

$$s3 = \frac{1}{-2a_v}\left(\ddot{v}_1 + \frac{a_v}{4} * t_s{}^2 + v_1 * a_v * t_s\right) \qquad \textbf{(2.50)}$$

Stopping time can be found by the summation of s1, s2 and s3.

S_stop = s1 + s2 + s3 **(2.51)**

$$s_{stop} = v_1 * \left(t_r + t_a + \frac{t_s}{2}\right) - \frac{v_1{}^2}{2 * a_v} + \frac{a_v}{24} * t_s{}^2 \qquad \textbf{(2.52)}$$

For this system timing, the third term of system can be negligible;

$$s_{stop} = v_1 * \left(t_r + t_a + \frac{t_s}{2}\right) - \frac{v_1{}^2}{2 * a_v} \qquad \textbf{(2.53)}$$

Total stopping time is derived from the formula below:

$$t_{total} = t_r + t_a + t_s + t_v \qquad \textbf{(2.54)}$$

"tv" is changed with the formula 2.48 and the formula 2.54 can be rearranged as 2.55.

$$t_{total} = \left(t_r + t_a + t_s + \frac{t_S}{2}\right) - \frac{v_1}{a_v} \qquad \textbf{(2.55)}$$

When there is a dangerous for the driver, the breaking system should work quickly, so the driver has a fast response to stop the vehicle. Consequently, breaking acceleration will be maximum for the condition. For the electric minibus, tr is 0.4 second, ts is 0.2 second, ta is 0.04 second. These timings are assumed for the campus path and the vehicle speed range is thought as 18 to 40 km/h. With these parameters, codes @Appendix 9 are written and necessary graphs are drawn as Figure 2.14.

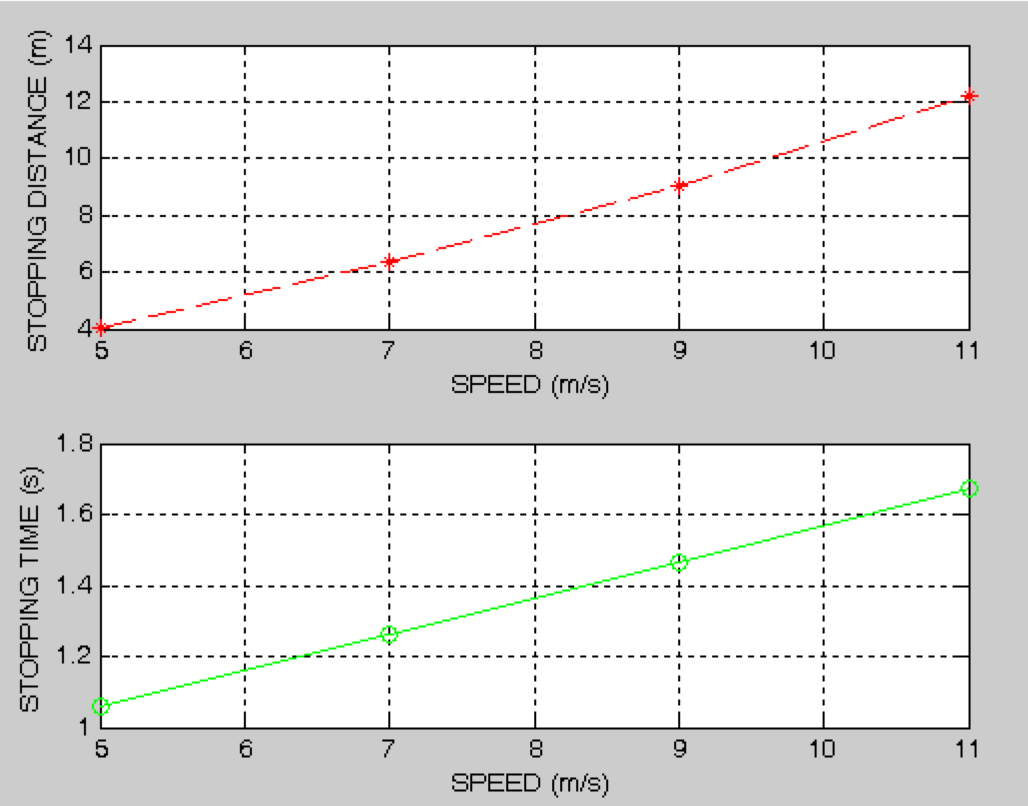


Figure 2.14: Stopping Speed & Time- Distance Graphs.

The maximum stopping time is 1.65 second, maximum stopping distance is 12.2 meter. Consequently, the distance to follow to another vehicle can be taken as between 12 and 14 meter.It changes fron driver to driver.

2.7 Road Curve and Corner Calculations

The vehicle characteristic at the curve is associated with the performance on the way and its type. Vehicle stability is enabled by the signals, which are sent by driver, and it is the easy way to control the vehicle. The vehicle and its driver can be thought as closed loop system. The vehicle turning of the curve can be thought as two types. These are:

1- Turning the Curve With Low Speed

2- Turning the Curve With High Speed

2.7.1 Turning the Curve With Low Speed

When turning the curve with low speed, center of turning should be the projection of rear axle. In addition to it, center of the front wheels should be also at the same point. The point is shown in Figure 2.15.

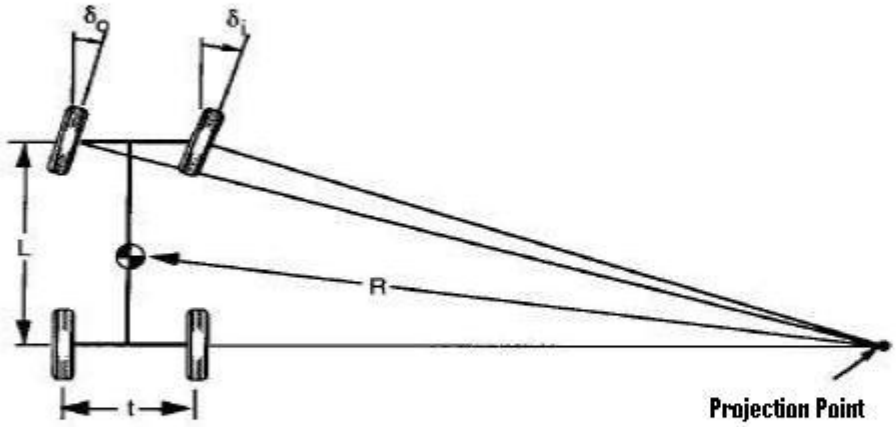


Figure 2.15: Projection Point.

L is the distance between the front and rear axles. t is the width between rear wheel left to rear wheel right. Front width is also same with it. δo is the wheel angle for front and left wheel. δi is the wheel angle for front and right wheel. These angles are called as Ackerman Angle.

$\delta o = L/ (R+t/2)$ **(2.56)**

$\delta i = L/ (R-t/2)$ **(2.57)**

The front wheel ackerman angle can be thougt as the same as δo and δi. It is formulated in formula 2.58.

$\delta = L/ R$ **(2.58)**

L is the distance between the axles and it is 330 cm for electric minibus. If the road curve is thought as 100 m, the Ackerman angle is:

$\delta = 3.3 \text{ m} / 100 \text{ m}$ **(2.59)**

$\delta = 0.033$ rad = 1.89 degree **(2.60)**

When the curve radius decrease, the ackerman angle is increase. If curve radius is 50 meter, the ackerman angle is shown below.

$\delta = 3.3$ m / 50 m **(2.61)**

$\delta = 0.066$ rad = 3.78 degree **(2.62)**

2.7.2 Turning the Curve With High Speed

When the vehicle turns the curve with high speed, the lateral forces are formed and lateral slip can occur. There is an angle between wheel direction and path direction which is called as Slip angle. The lateral forces are proportionally changed with slip angle and it can be described in Figure 2.16.

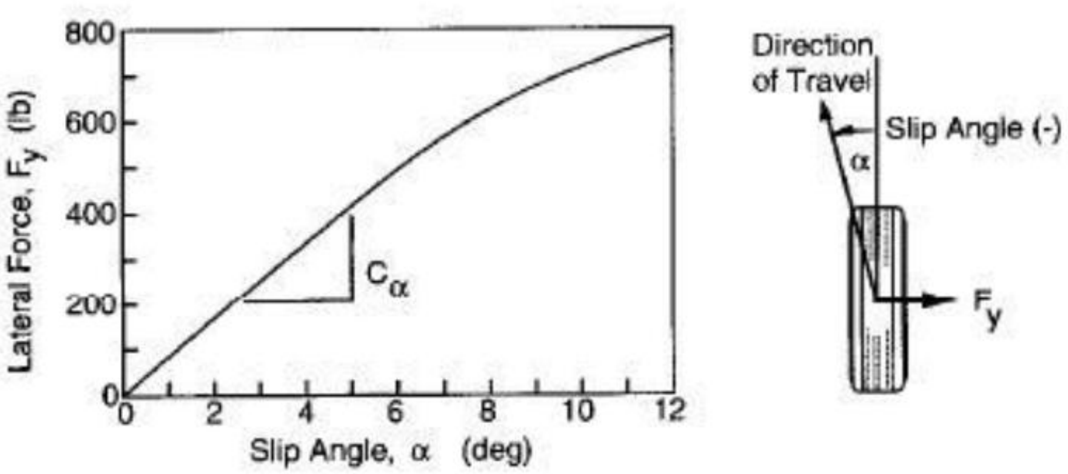


Figure 2.16: Lateral Force & Slip Angle Chart.

$C\alpha$ is the coefficient about the roughness of wheel. Fy can be formulated as:

$Fy = C_\alpha * \alpha$ **(2.63)**

2.7.3 Turning Equations

According to Newton's Second Law, sum of lateral forces should be equal to multiplication of mass and acceleration.

$\sum Fy = Fyf + Fyr = m_{wheel} * (V\text{^}2/R)$ **(2.64)**

$m_{wheel} * (V\text{^}2/R)$ is the centripedal acceleration. F_{yf} and F_{yr} are the lateral forces at the front and rear. In addition to it, the moment of lateral forces should be zero at the center of mass to satisfy the right momentum. Figure 2.17 shows the center of mass, the rear and front wheel position and their distances.

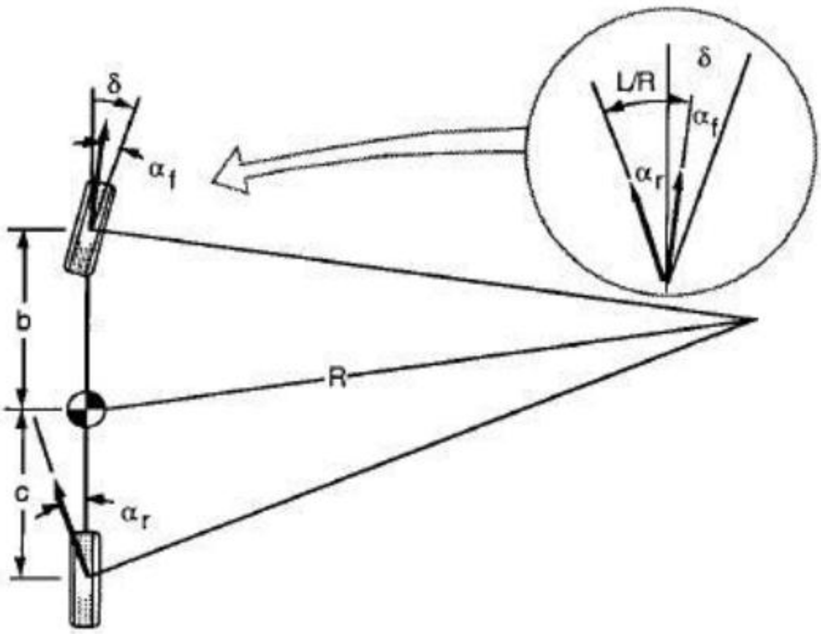


Figure 2.17: Wheel & Their Position on The Curve.

$$(Fyf*b) - (Fyr*c) = 0 \qquad \textbf{(2.65)}$$

$$Fyr = (m_{wheel}*b) / (L * (V^2/R)) \qquad \textbf{(2.66)}$$

“b” distance can be equal to “c” distance if the center of gravity of electric minibus is at the middle of minibus so the front and rear lateral forces are equal to each others.

$$b = c \text{ (for neutral steering vehicle)} \rightarrow Fyf = Fyr \qquad \textbf{(2.67)}$$

2.7.4 Steering

Steering is the term to the collection of components, which allow the electric minibus to follow the desired course. Steering can be occurred in three categories. These are under steering, neutral steering and over steering.

2.7.4.1 Under Steering

Under steering, is the case, which the vehicle goes out of the road curve and slip can occur. Driver should enable higher steering angle to provide desired steering curve radius. Desired steering curve radius produces the necessary lateral forces at the front wheels.

Understeering has a gradient shown as "K". The ackerman angle can be described with the formula which includes the understeer gradient.

$$\delta = 57.3 * (L/R) + K * a_Y \qquad \textbf{(2.68)}$$

a_Y is the lateral acceleration that affects the under steering. Under steering position can be described with Figure 2.18.

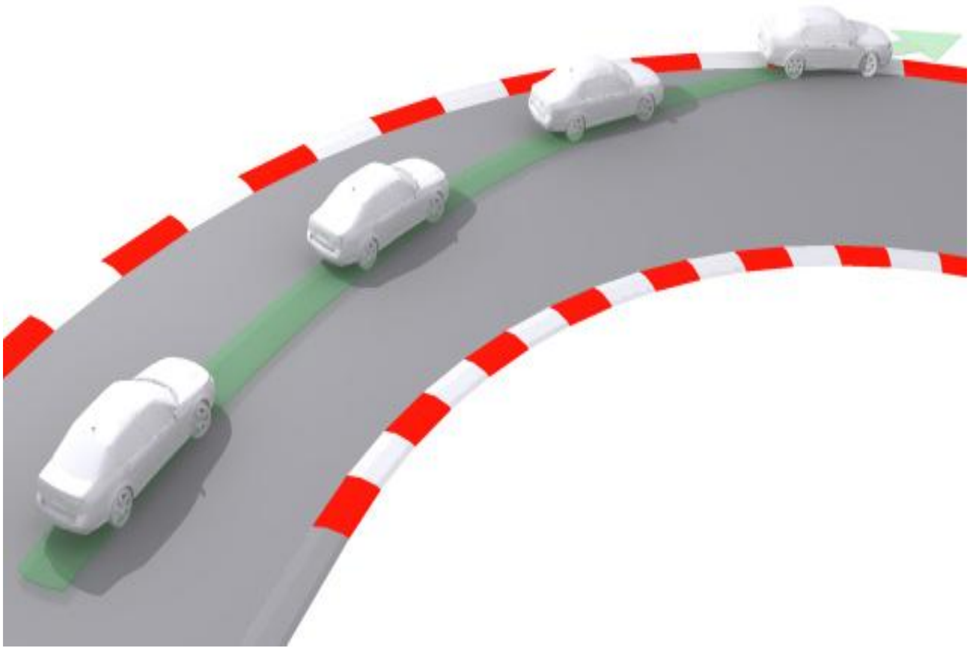


Figure 2.18: Under Steering.

$$[W_f / C\alpha_f] > [W_r / C\alpha_r] \; ; \; K > 0 \; ; \; \alpha_f > \alpha_r \qquad \textbf{(2.69)}$$

Under steering conditions are formulated as formula 2.69. Front wheel slip angle is bigger than rear wheel slip angle. Under steer gradient is bigger than zero.

2.7.4.2 Over Steering

Over steering is the condition that causes the slip of rear wheels so the rear part of vehicle goes out.

Front part of vehicle goes into the curve of the road. Steering wheel angle will be descreased when the vehicle condition is over steering. Slip angle and steering gradient is described in the formula 2.70.

$$[W_f / C_{\alpha f}] < [W_r / C_{\alpha r}] \;;\; K < 0 \;;\; \alpha_f < \alpha_r \qquad \textbf{(2.70)}$$

The Figure 2.19 shows the vehicle condition when it is over steering.

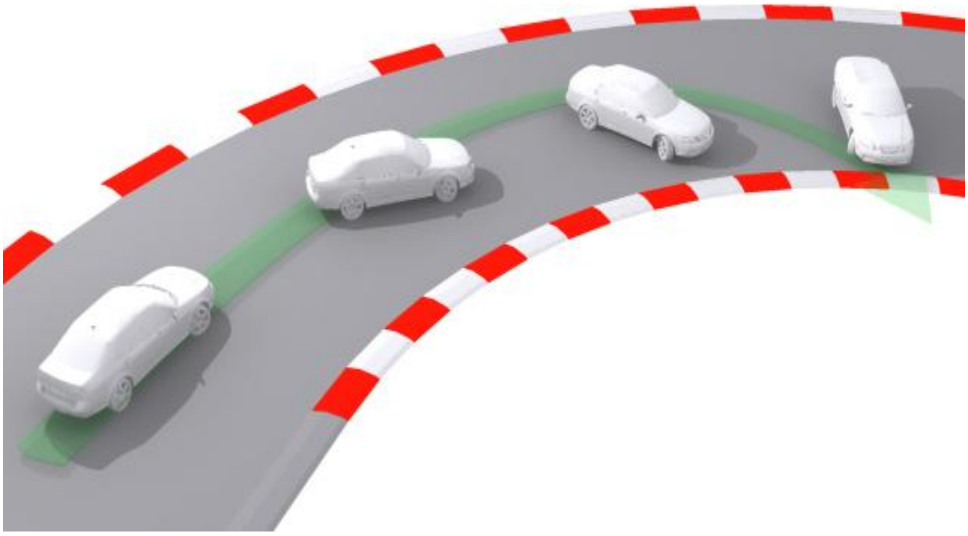


Figure 2.19: Over Steering.

2.7.4.3 Neutral Steering

When the vehicle turns the road curve, which has contant radius, the wheel radius is the same with Ackerman angle. Phsically, slip angle is increased at the all wheels equally due to the force at the center of gravity which is produced by lateral acceleration.Gradient is zero, slip angles are equal as shown in the formula 2.71.

$$[W_f / C_{\alpha f}] = [W_r / C_{\alpha r}] \;;\; K = 0 \;;\; \alpha_f = \alpha_r \qquad \textbf{(2.71)}$$

2.7.4.4 Electric Minibus Steering Type

Weight of electric minibus is distributed uniformly as the assumption so the center of mass is at the center of vehicle and the steering type of electric minibus is neutral steering.

2.8 Characteristic and Critical Speeds

Characteristic Speed is formed when the vehicle is under steering and ackerman angle of wheels should be two times greater.

$$K * a_y = 57.3 * L/R \tag{2.72}$$

$$Vcharacteristic = \sqrt{57.3 * L * (g/K)} \tag{2.73}$$

Critical Speed is formed when the vehicle is over steering and the vehicle is unstable.

$$Vcritical = \sqrt{-57.3 * L * (g/K)} \tag{2.74}$$

Wheel angle change with the vehicle speed and the critical and characteristic speeds are summarized with Figure 2.20.

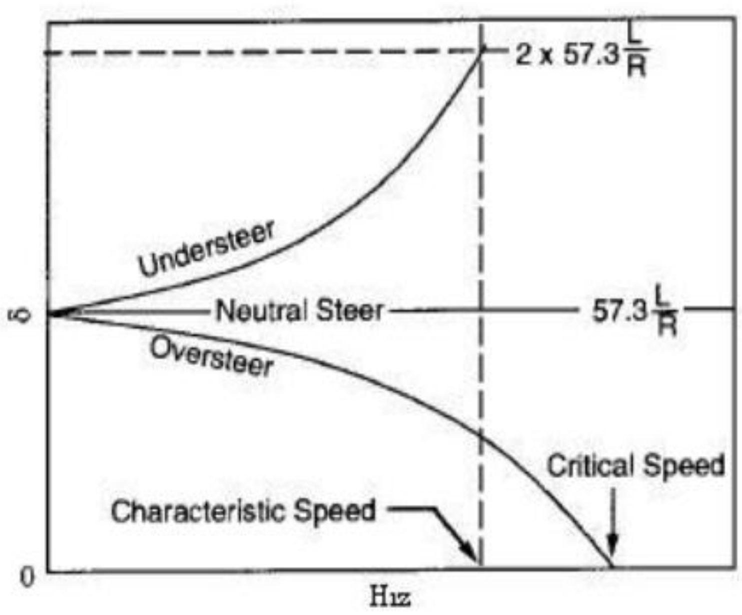


Figure 2.20: δ & Speed Graph.

Electric minibus steering is neutral steering so the ackerman angle can be calculated with the formula which is formulated at the Figure 2.20.

2.9 Rollover Calculations

Rolling is the situation that the vehicle body connects with the surface of way due to the instability. The rolling is caused by the rotation of longitudinal axes of vehicle with 90 degree or more than 90 degree. When the lateral acceleration increases more than the force, which is compensated by wheels, the rolling of vehicle, can do. The semi-static cases describe the situation clearly.

2.9.1 Semi-Static Rolling of Rigid Vehicle

When the vehicle is at the road curve, lateral forces are compensated by forces of centripetal acceleration. If there is a difference between these forces, the moment between them causes the rolling.

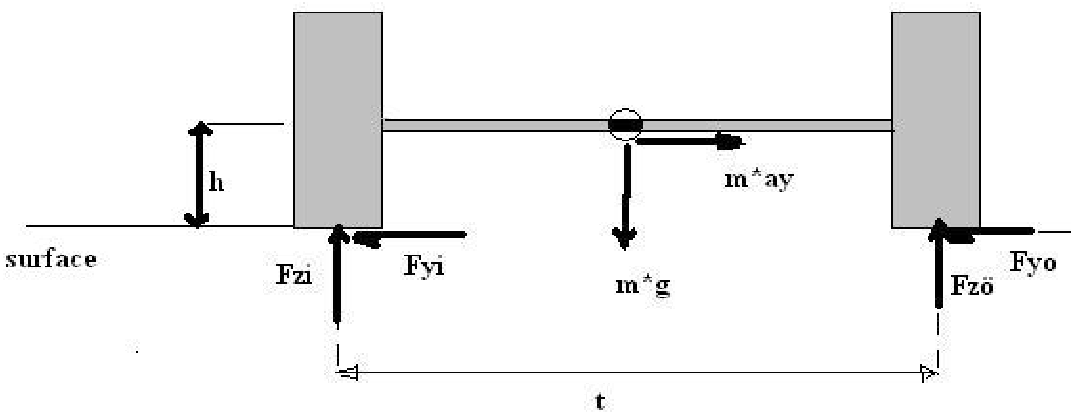


Figure 2.21: Forces @ Rolling Center.

When the moment of equation of the forces are written to the point of surface point of right wheel, the lateral acceleration value in which the vehicle rolls can be found.

$$(m * ay * h) - (m * \Phi * h) + (Fzi * t) - (m * g * (t / 2)) = 0 \quad \textbf{(2.75)}$$

The formula 2.75 provides the lateral acceleration formula which is 2.76.

$$(ay / g) = ((t/2) + (\Phi * h)) / h \quad \textbf{(2.76)}$$

This is the general rolling limit equation, which gives the nearest value. There can be experimental rolling values of the vehicles, which are shown in Table 2.9.

Table 2.2: Rolling Limit of Vehicle Types

VEHICLE TYPES	HEIGHT OF C.O.G	WIDTH	ROLLING LIMIT
SPORTS CARS	45-50 cm	130-150 cm	1,2-1,7 g
COMPACT VEHICLES	50-60 cm	130-150 cm	1,1-1,5 g
LUXURY AUTOMOBILES	50-62 cm	150-165 cm	1,2-1,6 g
LIGHT COMMERCIAL	75-90 cm	165-180 cm	0,9-1,1 g
MINIBUS	75-100 cm	165-180 cm	0,8-1,1 g
TRUCK	115-140 cm	165-190 cm	0,6-0,8 g
HEAVY TRUCK	150-215 cm	178-182 cm	0,4-0,6 g

2.9.2 Semi-Static Rolling of Vehicle With Suspension

When the vehicle with suspension goes to the road curve, load of internal wheels decreases and load of external wheels increases. Moreover, the center of gravity changes.

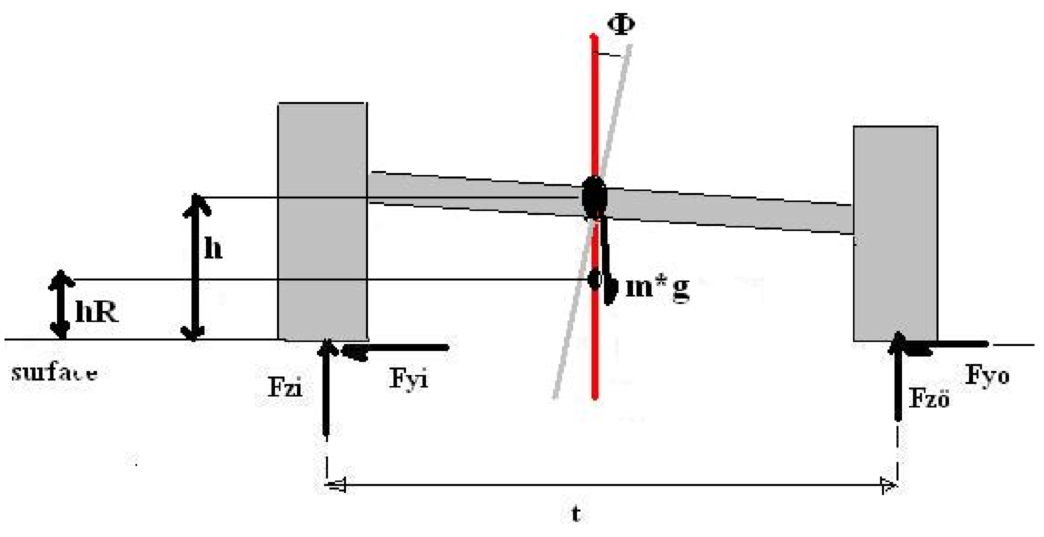


Figure 2.22: Forces of Rolling Center @ Road Curve

In Figure 2.22, the “h” is the height of center of gravity when the “hR” is the height of rolling center. “t” is the width between wheels of rear or front. The formula about the rolling limit of vehicle with suspension is formula 2.77.

$$\sum Mo= (m * g * ay* h) – (m* g *(t/2- \Phi(h-hR))) = 0 \quad \textbf{(2.77)}$$

$$(ay/g) = (t / 2h)*(1/ (1+R\Phi*(1-(hR/h)))) \quad \textbf{(2.78)}$$

As a conclusion, suspensions decrease the rolling limit value.

2.10 Vibration

Vehicles can be used with high speed and this causes vibrations. These vibrations are produced by the sources on the vehicle and the way so the vehicle characteristics give a response to these vibrations. The sources of vibrations are roughness of way, wheels, power train equipments and engine. After the vehicle gives a response to them, the driver takes these vibration responses and it is called as driver perception. The logical diagram for the vibration on the vehicle can be thought as open loop system and it is described as Figure 2.23.

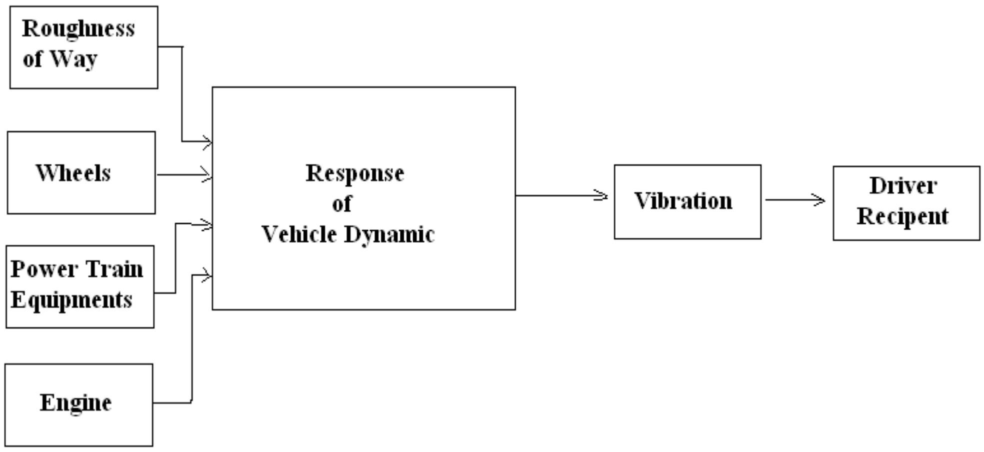


Figure 2.23: Logical Diagram of Vibration.

Roughness of way changes from way to way. The main concequential terms

are spectral density and wave on the surface which the wheels causes.

The second case is power train equipments. The most important power train equipment which causes the biggest vibration is axles. The length of axle increases the vibration. Vibration due to axles can be occurred by the unbalanced masses.The unbalanced masses are rotational parts, error of center of connection points, untrue axle structure, elasticity problem on the axles.

Thirdly, the engine is one of the biggest problem about the vibration because of the fact that is the power source and the pistons has the rotational loop so the torque value is not stable. Consequently, the vibration occurs when the engine starts. On the other hand, The electric minibus uses the electric motor so it has not any pistons and has a straightforward structure so the electric vehicle does not cause the vibration about it.

Considering everything, the vehicle should give a response to these vibrations so there can be spring-mass system. This system can be investigated with the responses which includes input-output signals. The system configuration is Figure 2.24.

Figure 2.24: Qurater Vehicle Model of Vibration System.

Ks is the value of roughness of suspension, Kf is roughness of wheel, VR is the vibration ratio. The VR can be described with the Formula (2.79)

$$VR = (Ks * Kf) / (Ks+Kf) \qquad \textbf{(2.79)}$$

When there is no damping on the system, the natural frequency is calculated with the formula below:

$$Wn = \sqrt{\frac{\mathrm{VR}}{\mathrm{m}}}(\mathrm{Rad/sec}) \qquad \textbf{(2.80)}$$

$$fn = 0{,}159\sqrt{\frac{\mathrm{VR}}{\mathrm{W/g}}}(\mathrm{cycle/sec}) \qquad \textbf{(2.81)}$$

If there is a damping on the system, the frequency is found by:

$$Wd = \mathrm{Wn}\sqrt{1-\xi^2} = \mathrm{Cs}/\sqrt{4 * \mathrm{Ks} * \mathrm{m}} \qquad \textbf{(2.82)}$$

ξ is the damping ratio and Cs is the damping coefficient of suspension which is between 0,2 and 0,4. The suspension absorbes the energy and the damper soakes this energy. The damper does not soaked the roughness of way, they sokaed the energy which are stored at the suspensions.

2.11 Traction Limits

When the power source of the vehicle which is electric motor for electric minibus is thought as unlimited, the movement of vehicle is limited by traction forces which comes from the physical limitations of minibus. The limitations includes inclination limits, acceleration limits, maximum trailer limits, slipping and rolling limits.

2.11.1 Inclination Limit

Electric minibus is front wheel drive vehicle. The inclination limit can be described with the formula 2.52. The vehicle parameters can be seen in Figure 2.2.

$$Tan\,\theta \leq \frac{\left(\frac{La}{L}\right) * \mu * \left(\frac{Lo}{L}\right) * fR}{L + \left(\frac{h}{L}\right) * (\mu + fR)} \qquad \text{(inclination limit)} \qquad \mathbf{(2.83)}$$

La & Lo are 1.65 meter when L is 3.3 meter due to location of the center of gravity which is at the middle of the vehicle. fR is calculated as 0.0138 in the part 2.4.1, μ is 0.7 from the table 2.2. With these parameters the calculation shows that θ is bigger than 2.2 degree. The maximum limit is mentined at the section 2.4.2 that is 8.53 degree. Therefore the inclination can be at the range:

2.2 degree < θ < 8.53 degree (for the better inclination condition) **(2.84)**

2.11.2 Acceleration Limit

The acceleration limit is also explained with the same parameters with the formula 2.83. This formula is also for front wheel drive vehicles like the electric minibus.

$$a \leq \frac{\left(\frac{La}{L}\right) * \mu * \left(\frac{Lo}{L}\right) * fR}{L + \left(\frac{h}{L}\right) * (\mu + fR)} * g \qquad \text{(Acceleration limit)} \qquad \mathbf{(2.85)}$$

Acceleration limit for the minibus should be between 0.8 g to 1.1 g as it shown in Table 2.9.

0.8 g < a < 1.1g **(2.86)**

2.11.3 Additional Trailer Limit

When there is a trailer at the back of the electric minibus, this trailer maximum limits can be described with the formula 2.87 which is for front wheel drive vehicles.

$$\frac{Wtrailer}{g} \leq \frac{\mu * \left(\frac{La}{L} - \left(\frac{Ltariler}{L} * \frac{Fz_{trailer}}{g}\right)\right) - fR * \left(\frac{Lo}{L} + \left(\frac{Ltrailer}{L + Ltrailer} * \frac{Fz_{trailer}}{g}\right)\right)}{1 + \left(\frac{h\_trailer}{L}\right) * (\mu + fR)} \quad \textbf{(2.87)}$$

The electric minibus does not use a trailer but if it uses trailer, the formula 2.54 can be used to understand the trailer weight limits.

2.11.4 Limits of Rollover and Slipping

The movement limits for electric minibus are explained as slipping to outer side of the inclination and rolling. Slipping to the outer surface can occur when the lateral forces are smaller than the friction of surface. The width of electric minibus is shown as “t” and height of the center of gravity is featured as “h”. The inclination angle is θ and the ratio of centripetal acceleration to gravitational acceleration is explained as “a_r”. The figure 2.25 shows the details with the parameters.

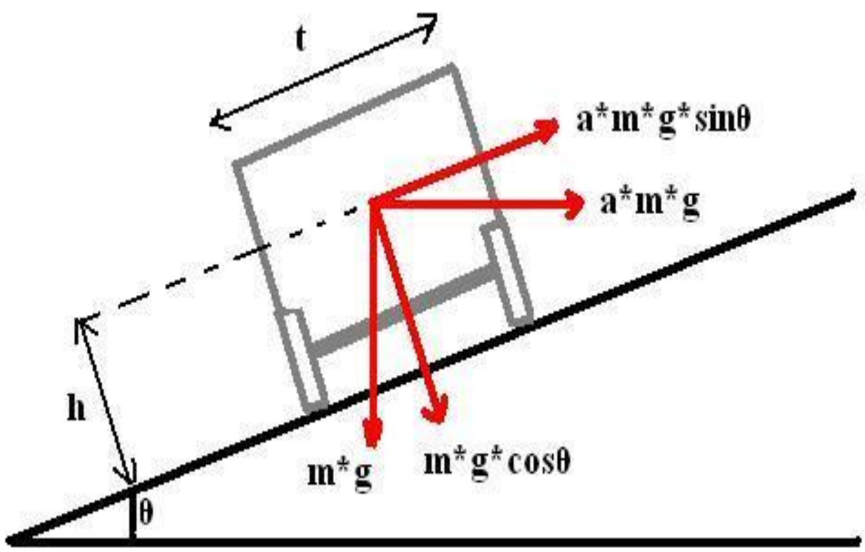


Figure 2.25: Vehicle @ Corner & Inclination

In the figure 2.25, the sum of total perpendicular forces is called as “Fp” and total forces on the surface of ground is decsribed with “Fg”. The formulas of them are below:

Fp = m*g* (cosα + a_r*sinα) **(2.88)**

Fg = m*g* (a_r*cos α – sinα) **(2.89)**

To protect the vehicle from slipping, the frcition factor (μ) should be greater than the ration of “Fg” to “Fp”.

$$\mu \geq \frac{F_G}{F_P} = \frac{m * g * (ar * cos\theta - sin\theta)}{m * g * (cos\theta + ar * sin\theta)} \quad \textbf{(2.90)}$$

From the formula, it is obvious to describe the “a” which is ratio of centripetal acceleration to gravitational acceleration with the formula below:

$$ar \leq \frac{\mu + tan\theta}{1 - \mu * tan\theta} \quad \textbf{(2.91)}$$

To enable the vehicle not to rollover, the resultants of centripetal forces and resultants of loads of vehicle should not get out of the strenght polygon.This is to say, the angles of vehicle dynamics about these polygon are α, β and γ. Their relation is below:

θ + β + γ = 90 degree. **(2.92)**

These angles can be described with the figure 2.26. The θ is positive slip angle, γ is the positive inclination angle and β is the angle between laeral force axis and spin axes.

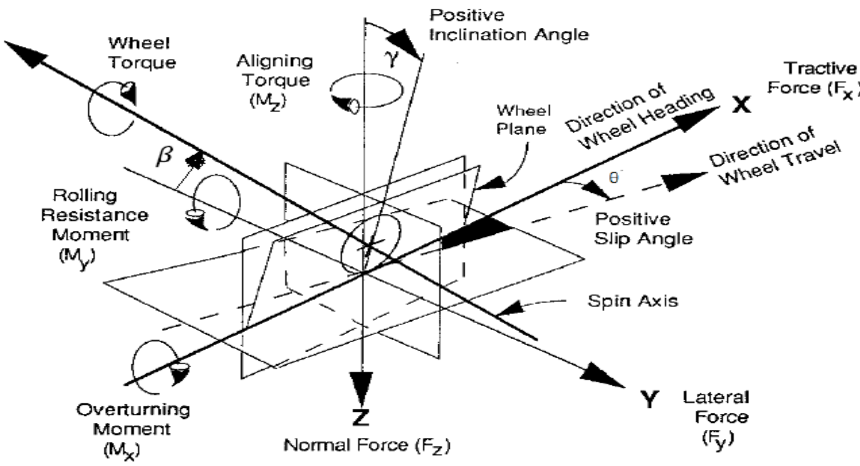


Figure 2.26: Angles of the Vehicle

In addition to them, the inclination angle can be described with he formula below:

$$\text{Cotan } \theta = (a*m*g) / (m*g) = a \qquad \textbf{(2.93)}$$

$$\text{Cotan } \beta = 2h / t \qquad \textbf{(2.94)}$$

According to trigonometric description;

$$\text{Cotan } (\theta + \beta + \gamma) = 0 \qquad \textbf{(2.95)}$$

Form this formula, "a" can be described with the formula below:

$$a \leq \frac{\frac{t}{2*h} + \tan\theta}{1 - \frac{t}{2*h} * \tan\theta} \qquad \textbf{(2.96)}$$

Taking everything into consideration, to protect the vehicle from slipping, θ angle and friction factor will have great values. The friction factor can be bigger with the parameters which are the materials of tire and surface of way. θ angle can have big values but there is a limitation about it because the vehicle can stop as stable when it is on the inclination. The limit is generally about 15 %.

Moreover, the θ angle should be big and center of gravity should be at the low height to enable vehicle not to rollover.Generally automobiles has a height of center of gravity as 0.5 meter maximum, the width of them are bigger than 1 meter. Consequently, the rollover limit is 1g as the worst case.

3. ELECTRIC MOTOR

3.1 Electric Motor In Vehicle Technology

The electric motors can be used in so many sizes and places, and there can be multitude of usage area such as refrigerators, electric shaver, electric toothbrush .In Vehicle Technology, electric motors used as an alternative of combustion engines or to make the vehicles range extender. The electric motors are ubiquitous because they are convenience that converts electrical energy into motion whether they are lifting, pushing, pulling or not. Moreover, the secret of them is reliability due to their simplicity that has two main parts: a rotor, which is moving part and the stator, which is stationary part [Figure 3.1]. If they are produced correctly, there is no failure or problem in use, generally. In addition to them, the electric motors are powerful that delivers peak torque near stall. This is to say, traction motors deliver peak torque near zero revolution per minute, so they have used in lots of vehicle technology and the internal combustion engines are not waiting with high performance like this. It is obvious that the electric motor performance is the best when it is compared with diesel or gasoline one. When the electric motor performance is between 85 % and 98 %, the diesel or gasoline engine performance is about 30 % and vice versa [1].

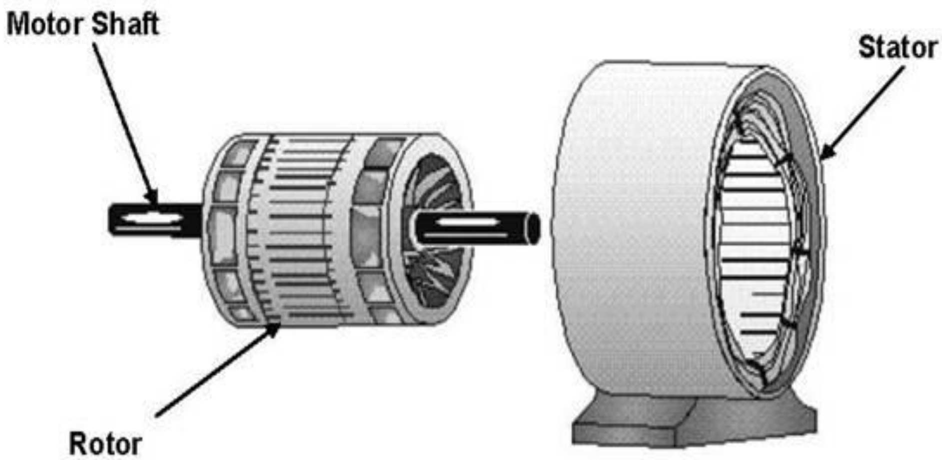


Figure 3.1: Electric Motor Base Structure.

3.2 Selection Of Electric Motor Type

One of the most important parts of electric vehicle is electric motor. The electric motor performance and its efficiency are directly affecting the vehicle performance, so the electric motor choice is a consequential factor. The electric motor selection criteria is related with the features of electric motor types when designing it.

AC and DC motors can also be used for electric vehicles. The electric motor types are investigated as shown in Figure 3.2.For these vehicles; the permanent magnet alternative current synchronous motors are generally used. Moreover, the permanent magnet direct current motors have a good controllability, linearity and straightforward structure. [3, 4] Next, their stability of operation is great and not only the speed but also the efficiency rate is high. The motor performance, size and cost are affected by magnet material enormously. [3] Likewise, brushless direct current motors are used in the fields with high performance and the low maintenance. Taking this information into consideration, the permanent magnet brushless direct current (PMBLDC) motors can be one of the best solution as the traction motor for electric vehicles.

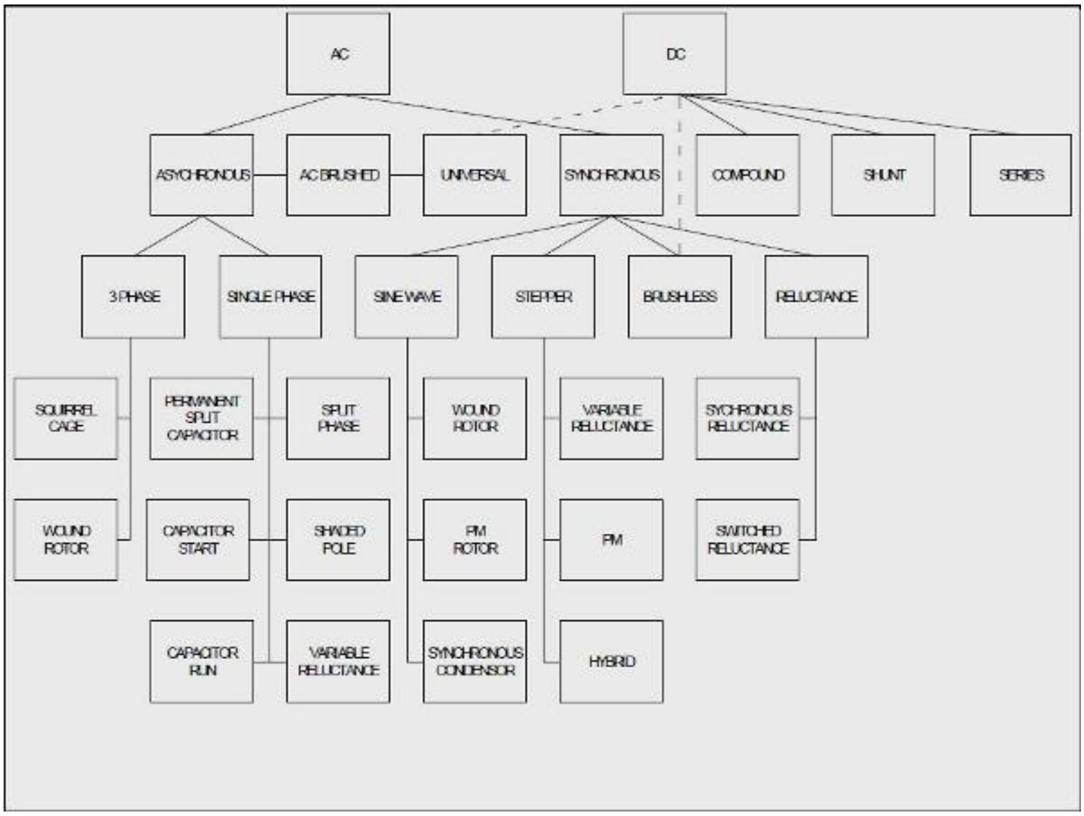


Figure 3.2 : Electric Motor Types.

3.3 Electric Motor Power Calculation

Power calculation of electric motor is based on the necessary power usage on electric motor which is transmitted to the driveline. The driveline includes electric motor, differential, drive shaft and drive wheels.

The electric motor is the power source in driveline. Engine torque (Te) is the output from the engine and the related engine speed is rotational speed [ωe].

The differential is a gearbox with a constant transmission ratio. It allows the speed difference between electric motor and drive wheel.

The drive shaft is connection equipment between the differential and drive wheels. The drive wheels convert the electric motor torque to traction force on the road. The input and output relation is shown in Figure 3.3. [5]

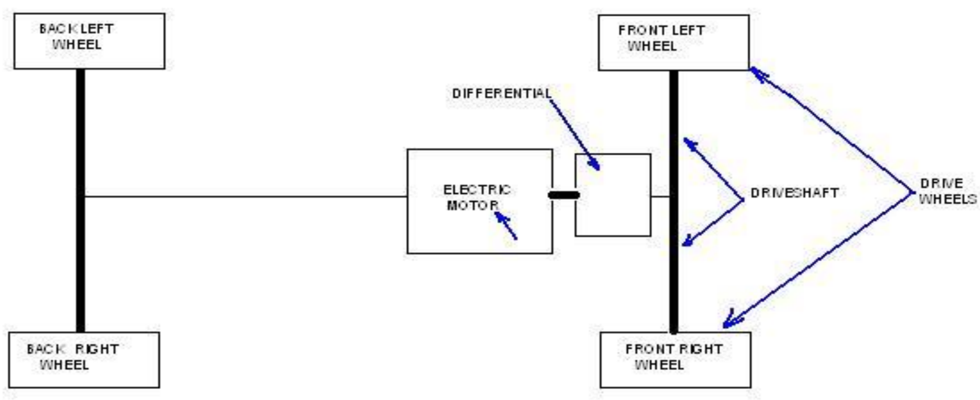


Figure 3.3: Driveline Equipments.

These driveline components in Figure 3.3 enable the adaptation of necessary torque and angular velocity to electric motor power.

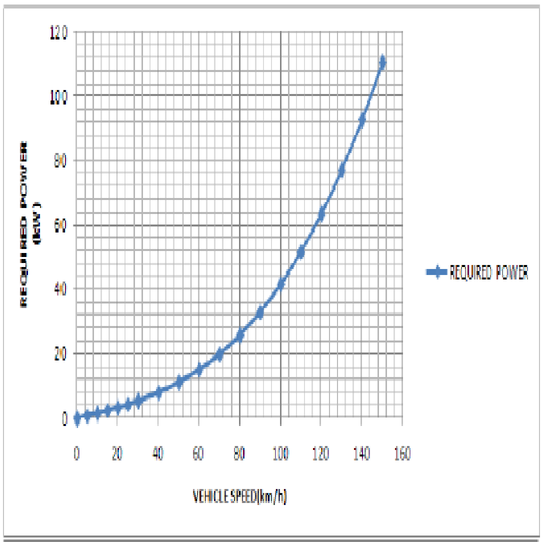
3.4 Electric Motor Selection

The selection of type of electric motor and the power calculations show us that the electric motor can be chosen as UQM 150 kW Traction Motor. The general properties of this motor are shown below Table 3.4.

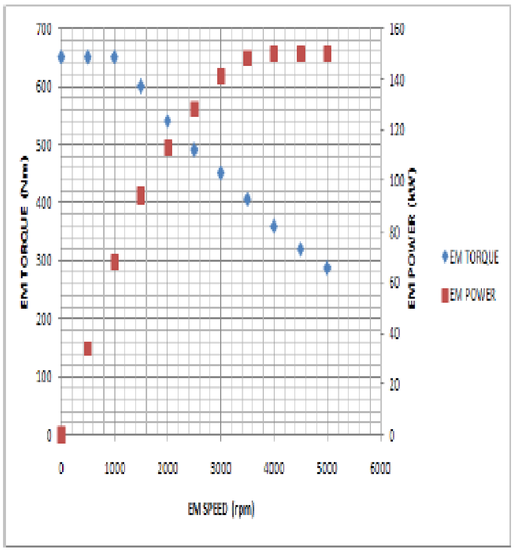
Table 3.1: UQM 150 Motor Properties

PowerPhase® 150 Traction System
650 N·m Peak Torque
150 kW peak, 100 kW continuous Motor power
Regenerative Braking
Full power @ 300-425 VDC Input
Custom Shaft Output Options
DSP-controlled inverter with sine wave drive
Maximum speed 5000 RPM

The necessary power& speed chart and motor chart about torque-speed & power are shown also at the bottom figure.(Figure 3.4)



Required Power & Speed Fig.



Electric Motor Torque-Power & Speed Fig.

Figure 3.4: Electric Motor Charts.

As it can be seen from Figure 2.10, when necessary power is 110 kW, electric motor power is 150 kW and vice versa. In addition to this, electric motor speed is 5000 rpm while the maximum speed of vehicle is 150 km/h.

Normally, the electric motor main values are explained in Table 3.2.

Table 3.2: Main Values of Electric Motor

Motor Devri (rpm)	Motor Torku (Nm)	Güç (kW)
0	650	0,00
500	650	34,02
1000	650	68,03
1500	600	94,20
2000	540	113,04
2500	490	128,22
3000	450	141,30
3500	405	148,37
4000	358	150,00
4500	318	150,00
5000	287	150,00

Section 2.5 explains the necessary power calculations about the vehicle dynamics and this power is described in Table 2.5. For the maximum speed, the necessary power at the flat road is 110 kw.

In addition to them, the necessary power calculations are investigated with the constant speed at the road with the gradient. The constant speed is 30 km/h and the gradient changes from 0 to 15 percentage which is 0 to 8.53 degree. The calculations is shown in Table 3.3.

Table 3.3: Necessary Power @ Road with Gradient With Constant Speed

Gradient (%)	Gradient (degree)	Rolling Resistance (Newton)	Air Resistance (Newton)	Inclination Resistance (Newton)	Vehicle Speed (km/h)	Vehicle Speed (m/s)	Total Resistance (Newton)	Necessary Power (kW)
0	0,000	576,207	81,760	0,000	30	8,333	657,968	5,483
1	0,573	576,207	81,760	421,875	30	8,333	1079,843	8,999
2	1,146	576,207	81,760	843,835	30	8,333	1501,802	12,515
3	1,718	576,207	81,760	1265,226	30	8,333	1923,194	16,027
4	2,291	576,207	81,760	1687,608	30	8,333	2345,575	19,546
5	2,862	576,206	81,760	2108,851	30	8,333	2766,818	23,057
6	3,344	576,206	81,760	2464,760	30	8,333	3122,726	26,023
7	4,004	576,205	81,760	2952,682	30	8,333	3610,647	30,089
8	4,754	576,204	81,760	3508,102	30	8,333	4166,067	34,717
9	5,143	576,203	81,760	3796,645	30	8,333	4454,609	37,122
10	5,710	576,202	81,760	4217,859	30	8,333	4875,822	40,632
11	6,277	576,201	81,760	4639,908	30	8,333	5297,869	44,149
12	6,842	576,200	81,760	5061,382	30	8,333	5719,343	47,661
13	7,407	576,199	81,760	5483,856	30	8,333	6141,815	51,182
14	7,970	576,198	81,760	5905,912	30	8,333	6563,871	54,699
15	8,531	576,196	81,760	6327,626	30	8,333	6985,583	58,213

When the vehicle travels at the campus one tour, the energy consumption is explained with the table 3.4.

Table 3.4: Used Energy Calculations From Vadi Dormitory to Natural Sc. Faculty

	Gradient (q)	Path Distance (m)	Speed (m/s)	Time (second)	Time (hour)	Used Energy (Wh)
Vadi Dormitory - Natural Science Faculty in ITU Maslak Campus Turkey	0,12	55	8,333	6,6	0,002	93,837
	0,05	275	8,333	33,0	0,009	211,363
	0,03	440	8,333	52,8	0,015	235,066
	0,08	110	8,333	13,2	0,004	20,075
	0,02	55	8,333	6,6	0,002	10,037
	0,06	110	8,333	13,2	0,004	20,075
	0,03	220	8,333	26,4	0,007	40,150
	0,04	165	8,333	19,8	0,006	30,112
	0,00	165	8,333	19,8	0,006	30,112
	0,02	110	8,333	13,2	0,004	20,075
	0,07	110	8,333	13,2	0,004	110,330
	0,08	55	8,333	6,6	0,002	63,651
	0,02	55	8,333	6,6	0,002	22,945
	0,04	330	8,333	39,6	0,011	215,020
	0,02	110	8,333	13,2	0,004	45,890
		Σ = 2365 m				Σ = 1168,738 Wh

The maximum used energy is 235 Wh which is used when the vehicle is at the gradient 0.05. Total used energy from the last stations is 1168.7 Wh. The used energy at the other path which is Natural Science Faculty to Vadi Dormitory is calculated at the table 3.5.

Table 3.5: Used Energy Calculations From Natural Science Faculty to Vadi

	Gradient (q)	Path Distance (m)	Speed (m/s)	Time (second)	Time (Hour)	Used Energy (Wh)
Natural Science Faculty - Vadi Dormitory in ITU Maslak Campus Turkey	0,02	110	8,333	13,2	0,004	20,074
	0,04	330	8,333	39,6	0,011	60,222
	0,02	55	8,333	6,6	0,002	10,037
	0,08	55	8,333	6,6	0,002	10,037
	0,07	110	8,333	13,2	0,004	20,074
	0,02	110	8,333	13,2	0,004	45,888
	0,00	165	8,333	19,8	0,006	30,111
	0,04	165	8,333	19,8	0,006	107,506
	0,03	220	8,333	26,4	0,007	117,528
	0,06	110	8,333	13,2	0,004	95,417
	0,02	55	8,333	6,6	0,002	22,944
	0,08	110	8,333	13,2	0,004	127,296
	0,03	440	8,333	52,8	0,015	80,296
	0,05	275	8,333	33	0,009	50,185
	0,12	55	8,333	6,6	0,002	10,037
		Σ = 2365 m				Σ = 807,653 Wh

When turning back from Natural Science Faculty, maximum used energy at the gradient 0.08 degree and total used energy is 807.7 Wh. Vadi Dormitory to Faculty travelling causes to use more energy than the travelling to Faculty to Vadi Dormitory.

3.5 UQM 150 TRACTION MOTOR

The UQM 150 Traction motor system is a state of art, standard motor package which is built for high performance and drive applications. Depending on the systems, motor power can be changed and for this application 150 kW is one of the choices. The motor system has a capability about of regenerative, four quadrant, bi-directional and torque controlled operation.[7]

3.5.1 Electrical Connections

The motor and controller electrical connections can be shown in Figure 3.5. Motor Leads A, B, & C are the phase connections which is three phases from motor to motor controller. Amphenol Connectors enables two different connections. One of them is rotor position cable which provides the rotor position information and the other one goes to hand control pad.

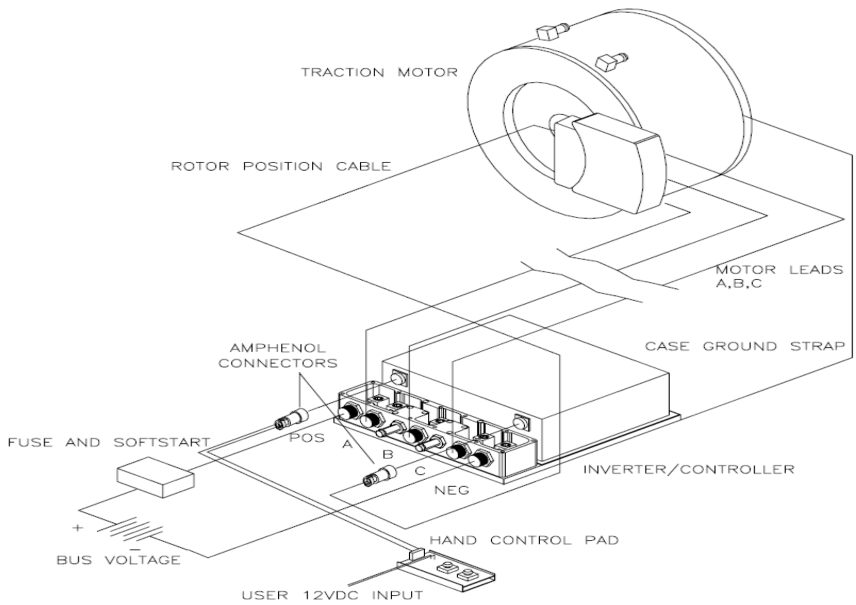


Figure 3.5: Electrical Connections of EM.

Hand Control Pad is the system to understand whether the electric motor works or not. This is only for the first step workings with the electric motor. After working with the hand control pad, the hand control pad should get out of the system and then the necessary electrical connection wires are connected to vehicle system. It can be seen in APPENDIX-1 that the electrical circuit interfaces and the necessary connections which are marked to connect the vehicle systems. The signals includes RS 232 connections, CAN communication connections, ground and supply voltages and 12 VDC signals. These signals are connected to vehicle system with CAN Circuit which is shown at the logical diagram in Figure 3.6.

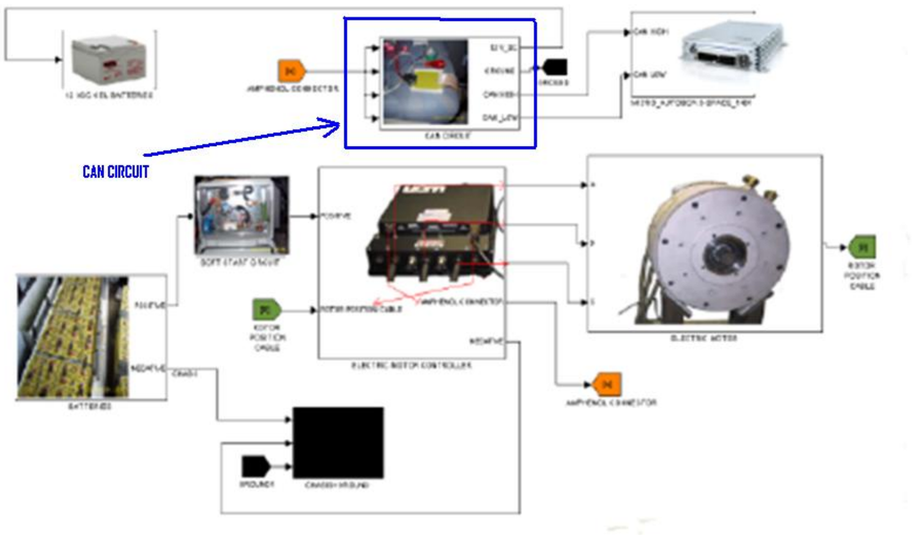
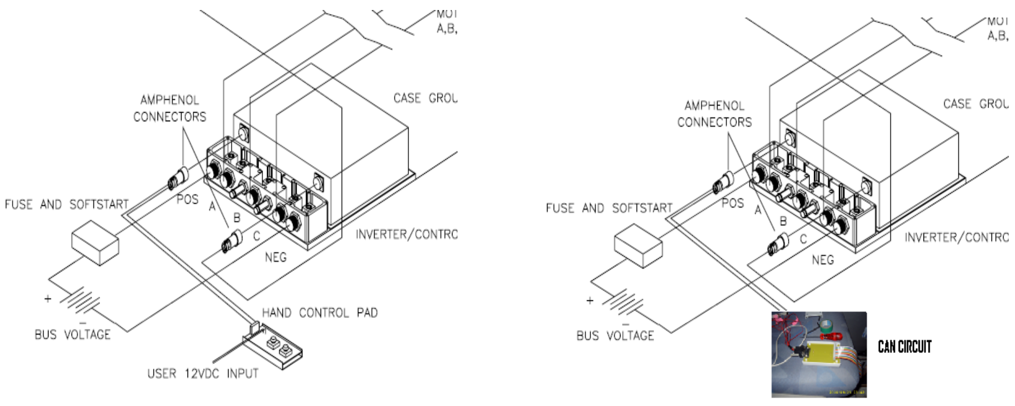


Figure 3.6: CAN Circuit in All Vehicle System.

The CAN circuit is replaced with the hand pad control connections and the related situation is shown in Figure 3.7.



At First Works with Hand Pad Control   Circuit at the Vehicle System

Figure 3.7: Motor Controller Connection.

In addition to them, power cable connections are enabled by the front part on the controller which is attached with the cable components shown in Figure 3.8.

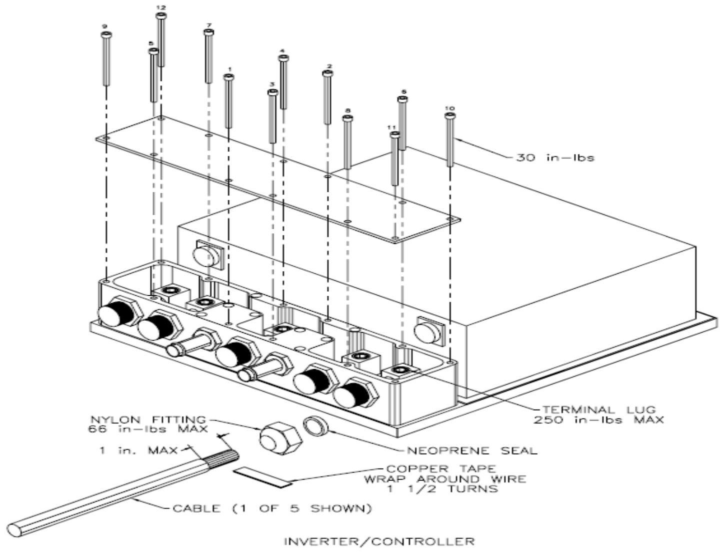


Figure 3.8: Power Cable Connection Area.

The terminal lugs or watertight fittings should not be tightened. Motor Cables A, B, and C are connected to their labeled terminals in the inverter. The Battery Cables Positive and Negative are also connected to their respective inverter terminals.

In Figure 3.5, the rotor position cable is also the temperature cable which has 15 pins and the 5 pins are about Hall Effect signals. 3 wires are used to send motor thermal information to microprocessor controller. Rotor position cable is connected to motor with 10 pins connector and is connected to controller with 15-pins connector. The rotor position cable at the controller side is shown in Figure 3.9.

Figure 3.9: Rotor Position Cable on Controller Side.

In Figure 3.5, it can be seen the Fuse and Starts called Start Circuit that must be avoid high and inrush current and protect the motor and motor controller. Charging of internal capacitances causes inrush current. The high inrush current decreases the Y2 contactor life and internal capacitors of inverter. The start circuit is shown below in Figure 3.10 as schematic layout and application view.

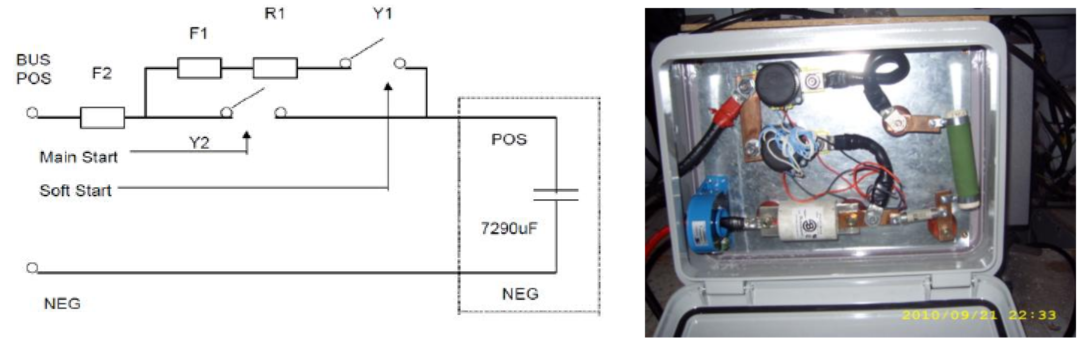


Figure 3.10: Start Circuit.

At Start Circuit, F1, Y1, R1 are the components of soft start and F2 and Y2 are the main start components. R1 is a resistor which has the 270 ohm resistance value and 65 watt power. This resistance and Y1 Contactor are used for the charging of internal inverter capacitors.Y1 and Y2 contactors are Gigavac gx14 type contactors and they have the maximum 750 volt and 350+ ampere continuous carry current. Its coil voltage is between 12 and 24 volt. The resistance has the 10 second waiting time. It can be between 100 to 750 millisecond. Moreover, F1 fuse is 300 Ampere and F2 fuse is 25 Ampere. F1 fuse size is selected to open if more than 1 second of time is required when charging internal inverter capacitors. F2 fuse and Y2 contactor are sized with respect to handle the voltage and current of the inverter. When the key of vehicle is turned on, the Y1 contactor is closed to operates the soft start circuit. Voltage sense circuit which is external to controller measures the voltage change on inverter capacitors. If the voltage on inverter is determined within 10 % of voltage of DC power, contactor Y2 is closed and system can be operated.[7]

3.5.2 Cooling System

The electric motor and its controller have a liquid cooling system. Coolant ports are sealed with o-ring material. Motor should have minimum flow rate of 7.5 lt/min to 15 lt/min. Maximum coolant loop pressure is 10 psi.

Coolant temperature range is -20 C degree to 55 C degree. A coolant flow rate of 7.5 lt/min can have a pressure drop of 3.2 psi because of controller and motor.

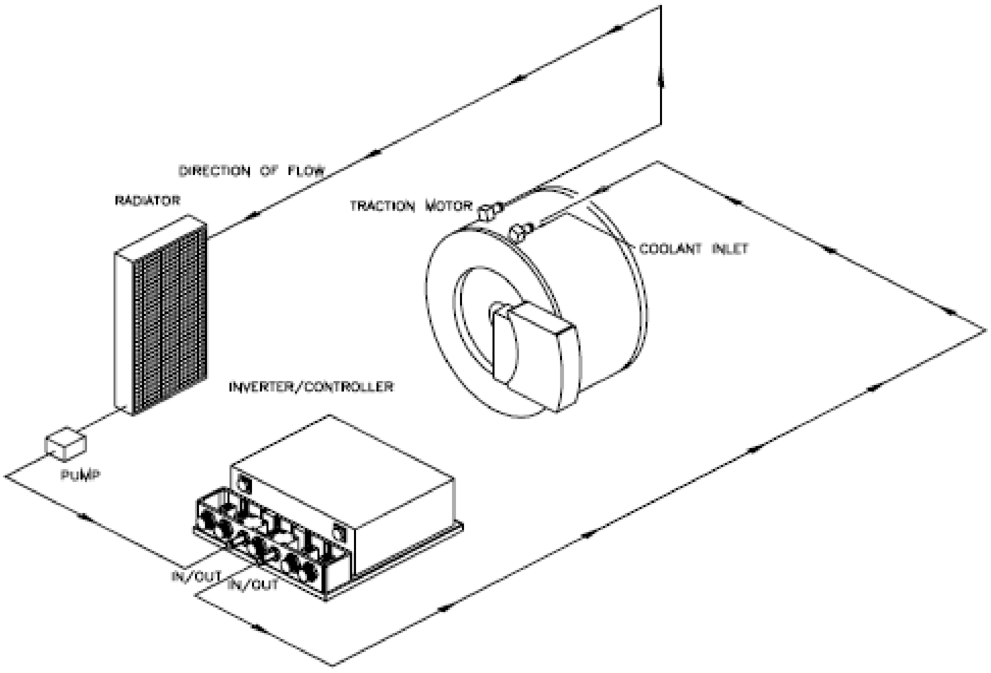


Figure 3.11: Cooling System Schematic.

In Figure 3.11, the schematic of cooling system is described. The motor and its controller should be lower than radiator fill port. The hose connections of motor are within 45 degree from the top which is for inlet and outlet ports for the coolant fluid.

The flow rate of fluid and pressure drop can be like at the bottom chart:

Table 3.6: Flow Rate& Pressure Drop

FLOW RATE gal/min	MOTOR psi	INVERTER psi	TOTAL psi
1	0.6	0.5	1.1
2	1.4	1.8	3.2
3	2.4	3.5	5.9
4	3.8	6.2	10

The necessary pump, radiator are chosen according to these properties. The cooling system on application is shown below in Figure 3.12.


Pump Place


Electric Motor Place


Motor Controller Place


Radiator Place

Figure 3.12: Cooling System on Application

3.5.3 System Operation

The UQM Electric Drive system includes PMBLDC Motor, a high power liquid-cooled inverter, and an internal Digital Signal Processing Controller. The Figure 3.13 shows the basic structure schematic.

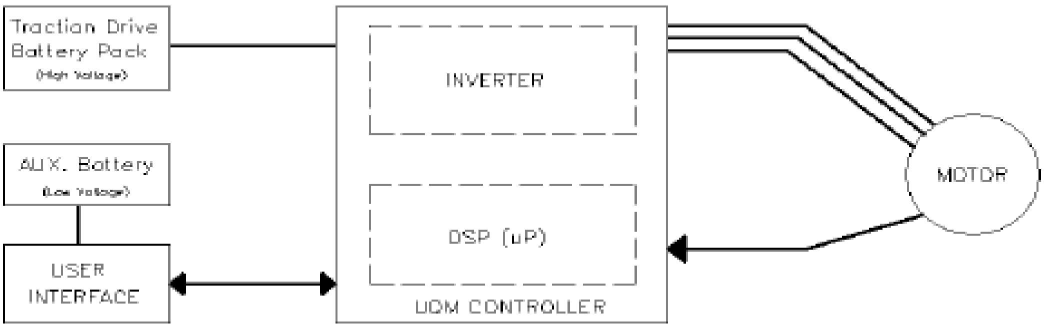


Figure 3.13: Electric Drive System Overview.

There are four types of control modes for the system. These are CAN Bus Control, Analog Torque Control, Analog Speed Control, Generator. The control commands are issued to controller and inverter via Can Bus. Torque, Speed, Voltage control are the main control types. The other type of control is analog torque control. Control commands are sent to controller and only torque control is possible. Analog Speed Control enables the control commands to send to controller and only speed control is possible. Finally, the generator is an autonomous control mode where no control commands are expected. It comes from system configuration.[7]

The electric minibus control mode is Torque Control. Command Torque is accelerator and Brake. When the accelerator is bigger than zero, and brake is smaller than zero, the torque profile for 100 % input command level is shown below in Figure 3.14.

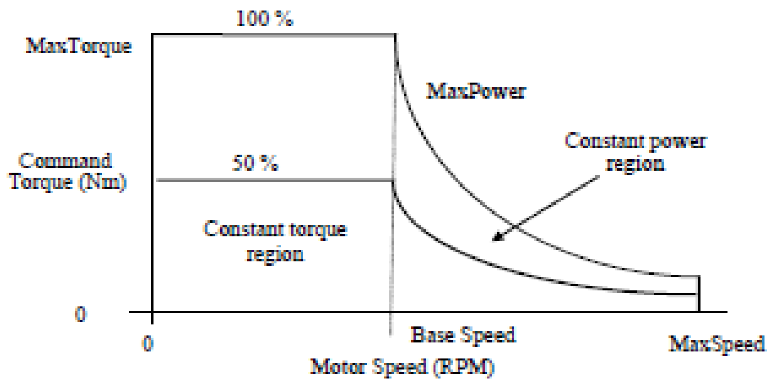


Figure 3.14: Torque Profile with 100 % Input Command.

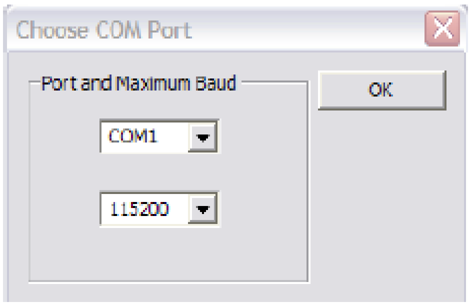
The torque curve enables to calculate the desired output torque. It is basically depended on the given input command. Command torque in Figure 3.14 shows the torque profile running at 100 % and 50 % command level. Command torque is associated with the motor speed as it can be seen in this figure. If the input percentage is less than 100 %, the maximum torque is going down based on percentage of command input.

The system load is necessary for the motor speed decision. The motor speed cannot be decided by the motor chart.

3.5.4 Motor Diagnostic Software

Motor Diagnostic Software runs on Microsoft XP. Motor and controller has software which enables the system to reorganize and the software communicates with the system with serial port. The software provides also controlling of can communication faults that the system can have. The software can be loaded to one portable computer and the necessary process can be done with this computer to the system. When the software is loaded to the computer, the communication port number is asked (see Figure 3.15) by the system and then the COM PORT might be selected. In addition to this, the baud rate is also asked and the baud rate should be the same with baud rate of vehicle controller side.

COM Port on Computer



COM Port and Baud rate on Software

Figure 3.15: Com Port & Baud rate on Software and Hardware

For the electric minibus, the baud rate is 115200 baud. It can be also chosen as lower rate. If the status is enabled, the communication message says the system is running. (System Status /See Figure 3.16)

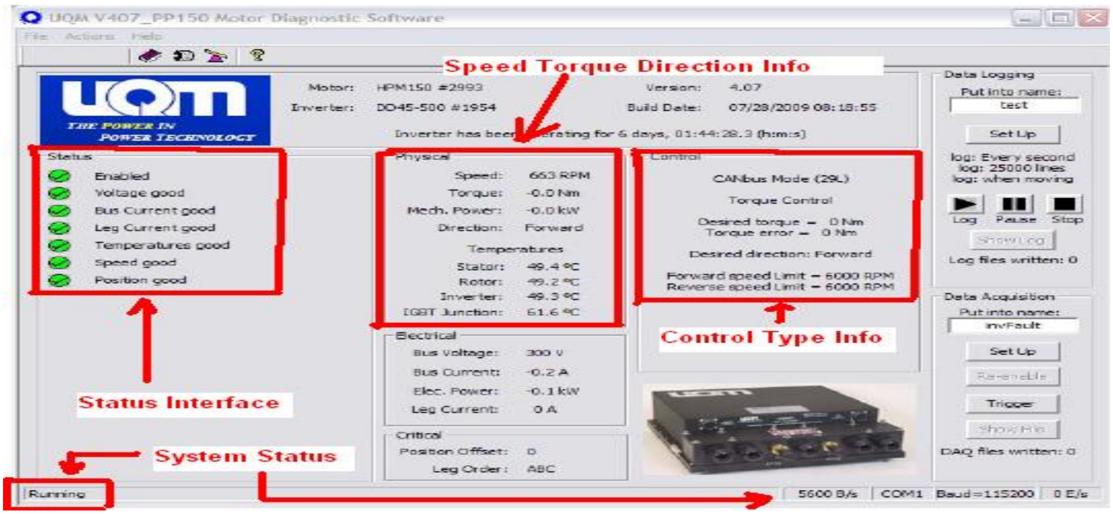


Figure 3.16: System Software User Interface.

Status Bar also shows the com port number and baud rate .Status interface includes 7 parameters which are enabled, voltage status, bus current status, leg current status, temperature status, speed and position status. “Enabled status” shows that the communication is enabled or not. “Voltage and current status” shows the voltage and current information can be taken by motor and its controller. “Temperature status” shows that there is no problem about temperature or not. “Speed and position status” provides to understand the vehicle can move or not. In addition to these, the speed torque direction info shows the speed and torque values that vehicle have. Next, Control Type information includes the serial communication or CAN communication can be enabled or not.

3.5.4.1 System Configuration Part

System Configuration part is accessed via Actions at the main page, it has three main parts which are General, Torque/Analogue, Digital/CAN.

3.5.4.1.1 General System Configuration

General System Configuration Parameters is shown in Figure 3.17.

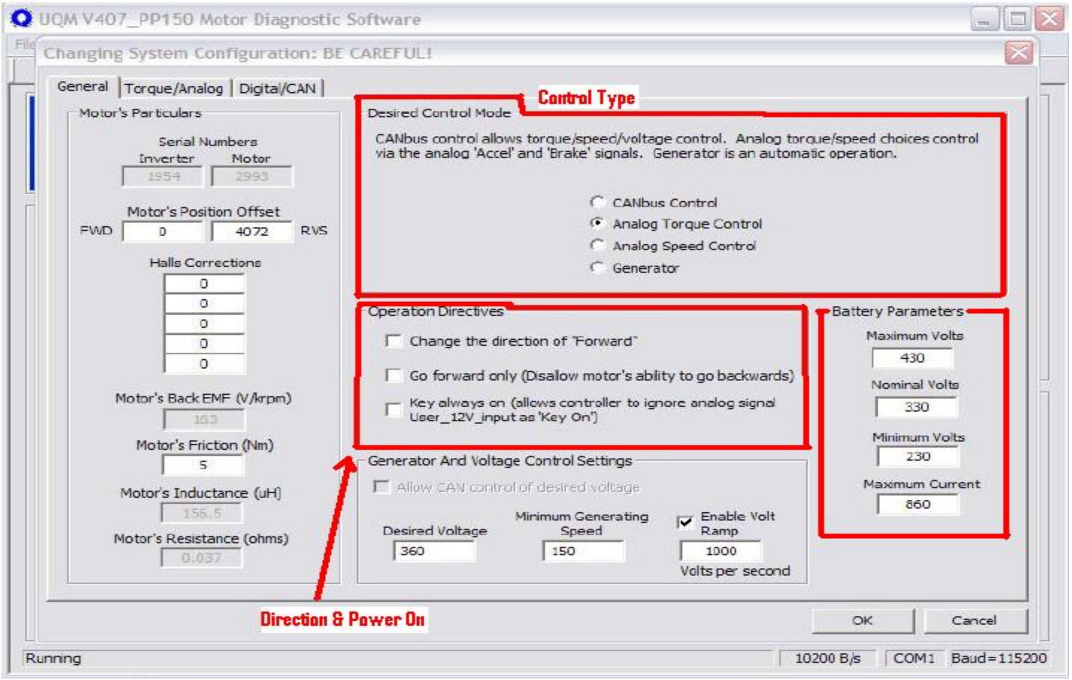


Figure 3.17: General System Configuration.

General system configuration includes control mode, decision of direction, power on and battery parameters. Direction and ‘Power on’ Part is about the power supply and direction of shaft of electric motor. Shaft of electric motor direction can be reversed according to its place on the vehicle. If so, the shaft is revolved at the inverse direction so the “Change the direction to Forward” button enables the revolution at the inverse side. Moreover, “Go forward only” button provides vehicle with only going forward. Next, “Key always on button” supplies the 12 V to the controller. Normally, Controller energy is provided by 12 V gel batteries. If this button is turned on, the controller energy is provided by whether 12 V gel batteries or LiFePo4 batteries which is used for electric motor power.

Battery Performance part includes maximum, minimum and nominal volts of battery packs and the maximum current of them. It can be restricted by this part.

3.5.4.1.2 Torque/Analogue Parameters

Torque analog part is in the System configuration part is shown in Figure 3.18.

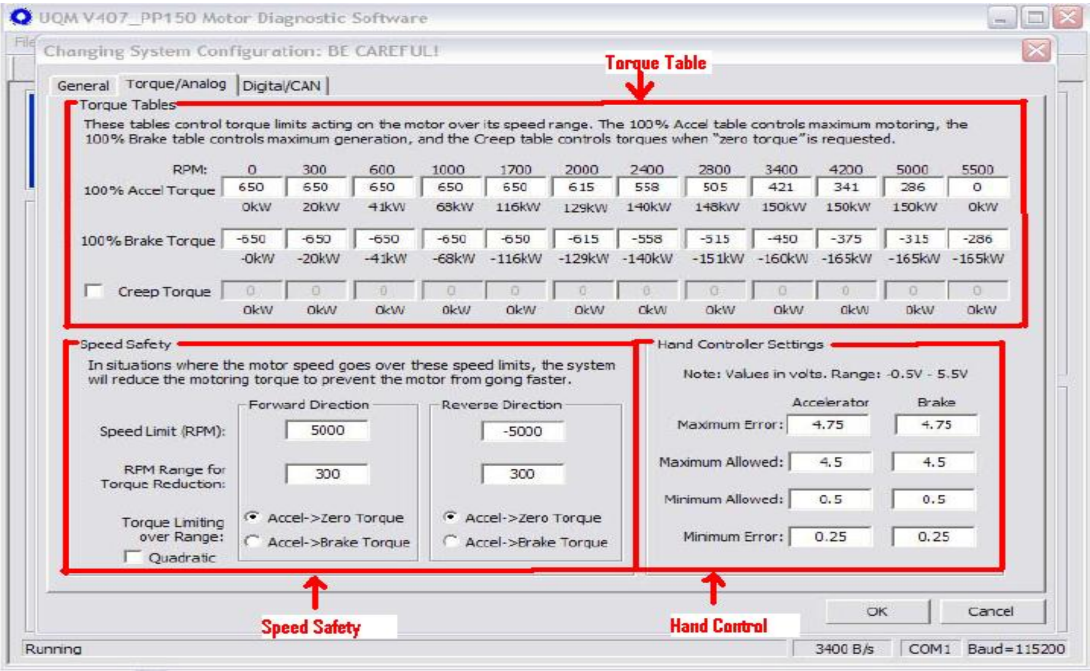


Figure 3.18: Torque/Analogue Interface.

Torque/Analogue part includes also three main parts which are torque table, speed safety and Hand Control Settings. Torque Table explains the acceleration and breake torque percentages with respect to speed of electric motor (rpm). The related speed can be changed from this software part.

The other part is speed safety in Figure 3.18. Speed Limit of the vehicle and reverse direction of speed can be limited from this part. Torque reduction can also be done.

The last part of Figure 3.18 is about Hand Control Setting which is mentioned that is for the first works with electric motor. It aims to understand the electric motor works or not.

3.5.4.1.3 Digital/CAN Bus Part

The last part of System Configuration is Digital/CAN Bus part. This part includes CAN Message type, Addresses, Drive mode and baud rate and transmitted information. The interface is shown in Figure 3.19.

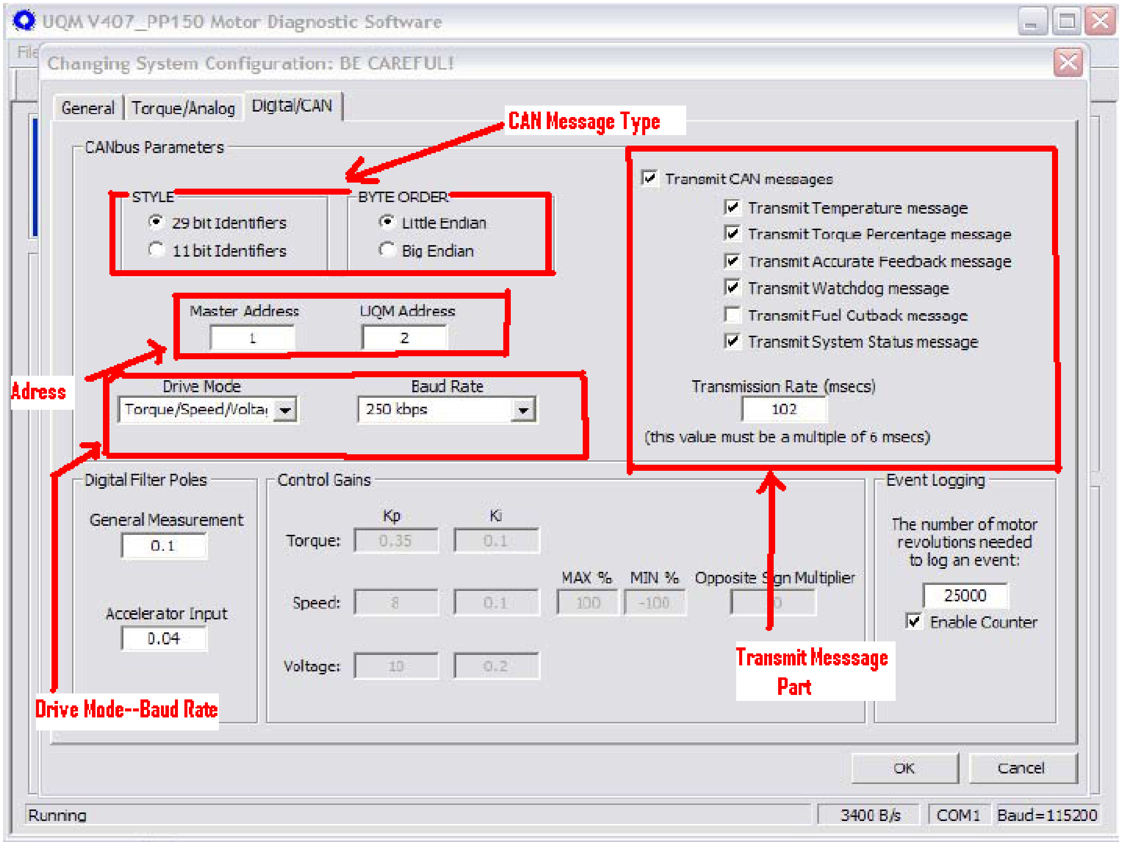


Figure 3.19: Digital/CAN Bus Interface.

The CAN Message type of the electric minibus is 11 bit Little Endian. CAN Network address of 0 to 255 when using 29 bit identifier while the 0 to 127 when using 11 bit identifier.

This is to say, if the electric motor is used for lots of condition and situation, identifier should be 29 bit but for the electric minibus, the electric motor usage is known and there are no different usage cases for the electric motor so the 11 bit identifier is needed.

The address part includes the master address and UQM motor address. When the message is sent, the motor address can be defined so the UQM address is used. In addition to it, when the message is sent, the master address is used in 29 bit identifier only. The 11 bit identifier does not use the master address because of the fact that it has only one receiving address. But, as it is emphasized, 29 bit identifier is used for lots of condition so there can be more than one master address.[8]

The electrıc minibus address algorithm is shown in Figure 3.20.

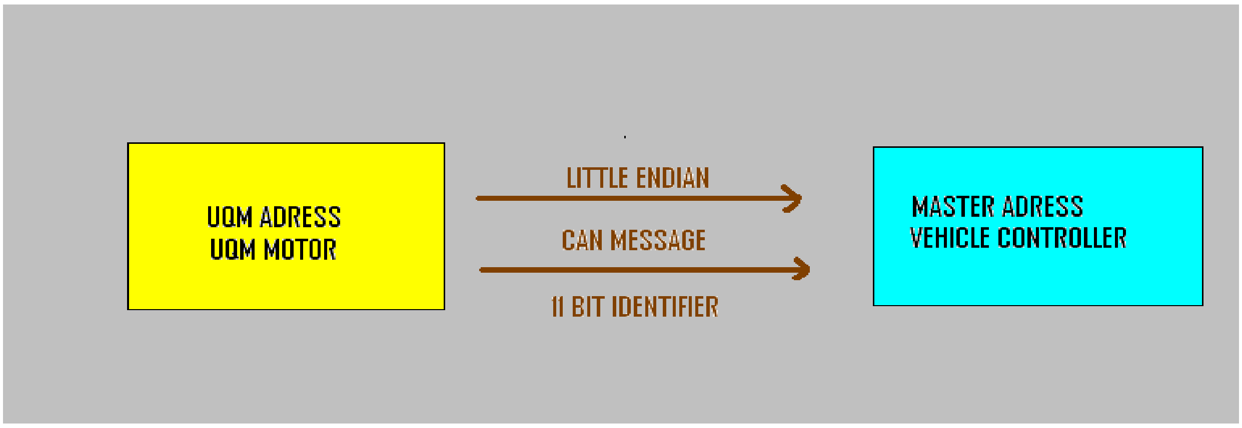


Figure 3.20: Digital/CAN Bus Message Algorithm of Minibus.

In Figure 3.19, drive mode part describes the motor drive types which are torque, speed, voltage control. The electric minibus is controlled by torque mode and it includes the vector control. Baud rate is the speed of sending message and its unit is kbit/sec. The electric minibus baud rate is 500 kbit/sec. The message baud rate is not the same with the software baud rate. The software baud rate is 115200 bit/s and the message baud rate is 500 kb/sec.

Transmit part shows the feedback information that are wanted to take after message is sent. It includes; temperature, torque, accurate feedback, watchdog, fuel cutback message and transmit system status.

3.5.4.2 CAN Communication File

The CAN communication is enabled by CAN Db file.[8] If this file does not exist, the engineer should create all CAN data and messages and all its properties. This is really hard issue to make so the easy way to continue is to use the CAN Db file. The file is in the set up cd of Motor Controller software and it is introduced to software diagnostic. The necessary process can be done at the first page of Diagnostic software in Figure 3.16. In the file or action part, there is an icon about it.

4. BATTERY AND BMS SYSTEM

4.1 Battery Technology in Vehicle System

The battery is an important power source in vehicle technology. The first charged battery is Pb-PbO2 batteries which are invented in the 1900's. The demand for fossil fuels for transportation and petroleum & the reduction of vehicle emission cause to find the alternative energy sources so the electric vehicle developments could be investigated. This also causes the researches and developments of traction batteries for Electric Vehicles.

In Fact, the features of traction batteries can have these properties:

- High Energy Density to provide long range
- Battery is built with safety mechanism
- High energy density provides the good acceleration and power capability
- Long life cycle is necessary
- Environmental friendly batteries should be used
- Less maintenance problems are required

Energy Institutes and Power research Centers have been formed to accelerate the development and research of technological batteries in advance to use in Electric Vehicles. The aim is to make the electric vehicle be competitive with conventional ICE.[1] Conclusively, the battery technology can be summarized in Figure 4.1 that includes the efficiency of the batteries. The Lithium based batteries are advanced batteries due to specific power and energy which are higher value in it.

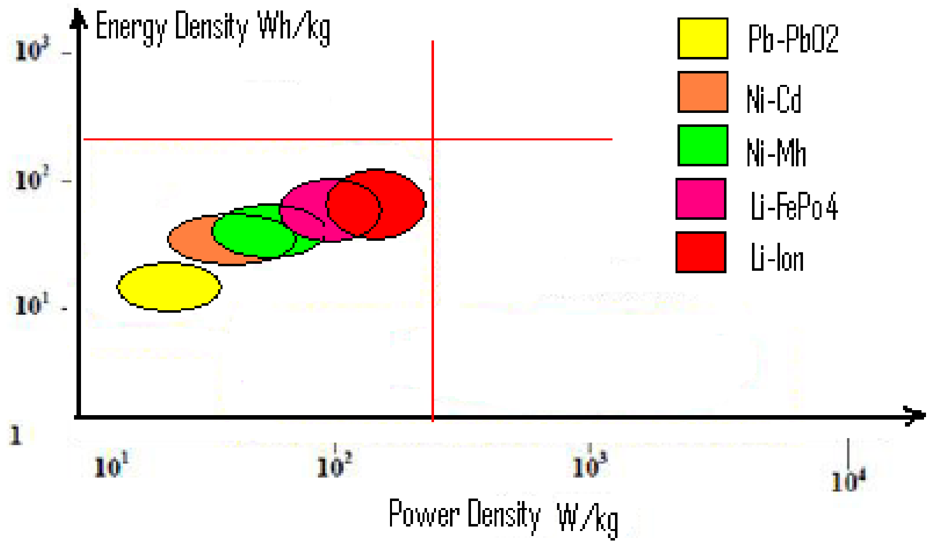


Figure 4.1: Specific Energy & Specific Power Chart.

4.2 Selection of Battery Type

Technical properties of the batteries which are Pb-PbO2, Ni-Cd, Ni-Mh, Zn-Br2, Na-NiCl, Na-S, Li-Ion, Li-Fe-Po4 is shown in Table 4.1.

Table 4.1: Battery Types & Specific Properties [10]

Properties/Battery Type	Pb-PbO2	Ni-Cd	Ni-MH	Zn-Br2	Na-NiCl	Na-S	Li-Ion	Lİ-Fe-Po4
Working Temperature °C	0 to 45	0 to 50	(-40) to 50	20 to 40	300 to 350	300 to 350	(-40) to 60	(-45) to 85
Specific Energy Wh/kg	161	236	300	430	794	795	275	250
Energy Density Wh/l	60 to 80	60 to 90	100 to 150	60 to 70	110 to 120	120 to 130	150 to 200	120 to 175
Specific Power W/kg	75 to 100	120 to 150	140 to 200	80 to 100	150 to 200	150 to 200	350 to 400	250 to 340
Cell Voltage (charged)	2.1	1.35	1.35	1.79	2.58	2.08	3.6	4

In this century, the lithium ion and lithium polymer batteries are the most technological batteries in advanced technology. [10] They are portable and their efficiency is better than the other batteries. On the other hand, there is another battery type which is also lithium based called Lithium Iron Phosphate Batteries.

As it is shown in Figure 4.1 & Table 4.1, the Lithium Ion batteries has better specific energy and specific power than the LiFePo4 batteries. But Lithium iron phospat batteries compensate the situation with lower capacity loss in long time period. They also have the best cell voltage and good temperature range. In Electric minibus application, the LiFePo4 batteries are used as a power source for vehicle and electric motor.

4.3 External Effects on Battery Efficiency

Another important issue is the effects on the batteries. The main issues are frequency of charge and discharge, discharge rate, operating conditions, charge rate, battery storage. The effects are summarized in Figure 4.2.

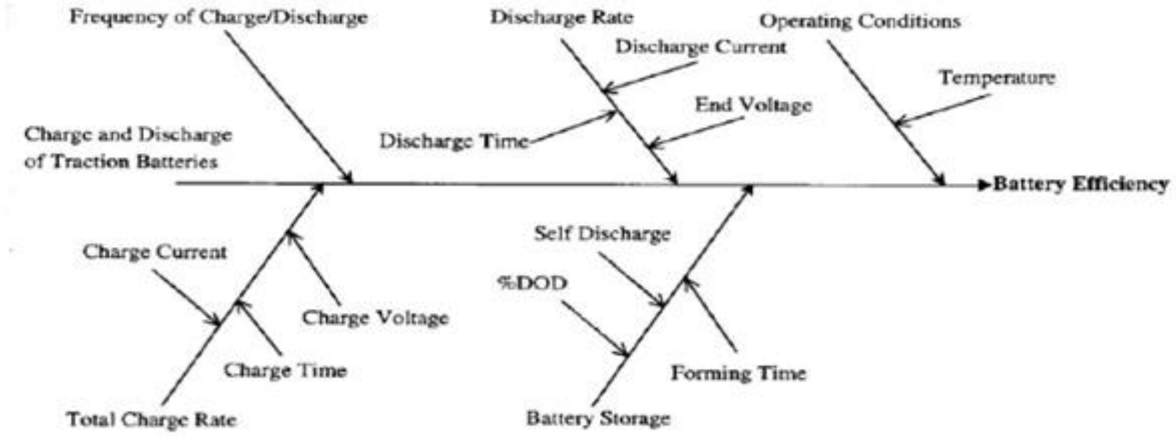


Figure 4.2: Effects on Battery Performance.

Battery efficiency is affected by charge and discharge rate, which includes the charge & discharge time, current, and voltage. In addition to them, temperature can cause the chemical and physical problems on batteries.

4.4 Characteristics of LIFEPO4 Battery on Application

In Electric Minibus application, the battery effects can be summarized. Power source is “Thunder Sky LiFePo4” batteries. There are 100 cells that are used in minibus. Operating Voltage for charge is 4 volt and 2.8 volt for discharge. Maximum charge current is smaller than 3 CA.CA has a meaning of capacitance and the unit ampere. C is 160 Ah for the unit cell in this application.

Standard charge and discharge current is 0.5 CA.[11] The lifecycle of batteries is minimum 3000 times when the depth of discharge is 80 %. Temperature range is between -45 C degree and 85 C degree. Weight of the batteries is 5 kilos. The nominal capacity, number cells and nominal voltage are the parameters which enable to calculate the nominal power that the vehicle is used.

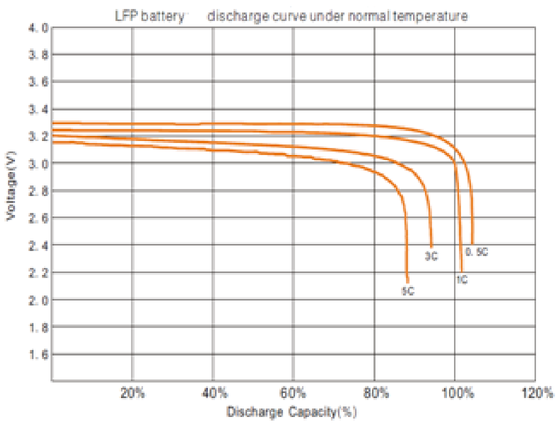
Power (P) = Capacity(C)* (# of Cells)* Nominal Voltage ($V_{nominal}$) **(4.1)**

P= 160 (Ah)* 100 Cells * 3.3 volt **(4.2)**

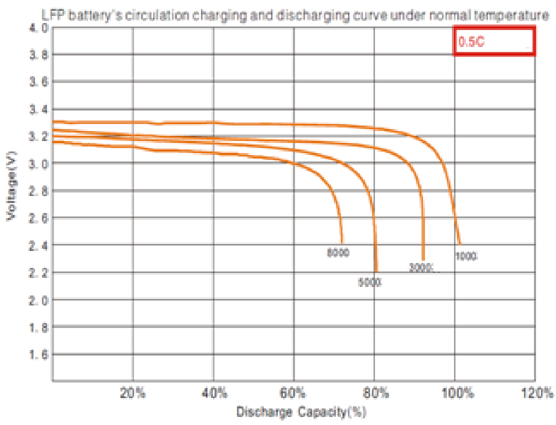
P= 52,8 kWh **(4.3)**

Conclusively, 52.8 kWh batteries are used in the electric minibus application.

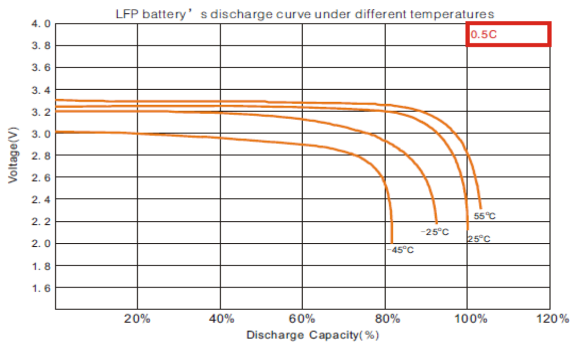
Moreover, the life time cycle can be determined from the battery graphs which are about discharge capacity and voltage. The Figure 4.3 shows them with respect to temperature and life cycle time.



'C' Rate Based Graph



Life Cycle Based Graph



Temperature Based Graph

Figure 4.3: Discharge Capacity & Voltage Charts.

In the temperature based graph, discharge capacity should be 80 % because the basic process is C rate is multiplied with 0.5. The 160 Ah is the nominal capacity of the battery cells.

Discharge Capacity (DC) % = (0.5)*(160) → DC= 80 % **(4.4)**

At the room temperature which is 25 C degree, the discharge rate that is 80 % is intersected the nominal voltage of 3,3 volt. With this information, if the life cycle based graph is investigated, the intersection of discharge capacity and nominal voltage gives the 3000 life time cycle.

The Lithium Iron Phosphate battery types has a chemical structure which includes Iron, Phosphate, Mn, Ca, Graphite, Na, C, Li, PE, Cu, Al, Lix, F. Their percentage are shown in Table 4.2.

Table 4.2: LFP Chemical Structure

LFP	
Chemical Element	Index
Fe	42%
P	16%
Mn	0.5%
Ca	0.3%
Graphite	5%
Na	0.01%
C	3.1%
Li	3.4%
PE	3.3%
Cu	10%
Al	6%
Lix	8%
F	3.3%

The temperature range is also investigated for three situations which are storage, discharge and charge. When the batteries are in storage, continuous temperature is 30 C degree as a maximum value. Occasional temperature for storage is between the range of -45 to 85 C degree. During the discharge, the continuous temperature is between 30 C degree to 85 C degree and occasional temperature between -45 to 85 C degree. In addition to them, the continuous and occasional temperature is between 0 and 75 C degree during charge.[11]

4.5 Assembly and Package

The LiFePo4 batteries in this application has a hundred cells and they are packaged as twenty packages. One pack includes 5 cells so the battery system can be composed after the system integration. The battery pack system is shown in Figure 4.4.

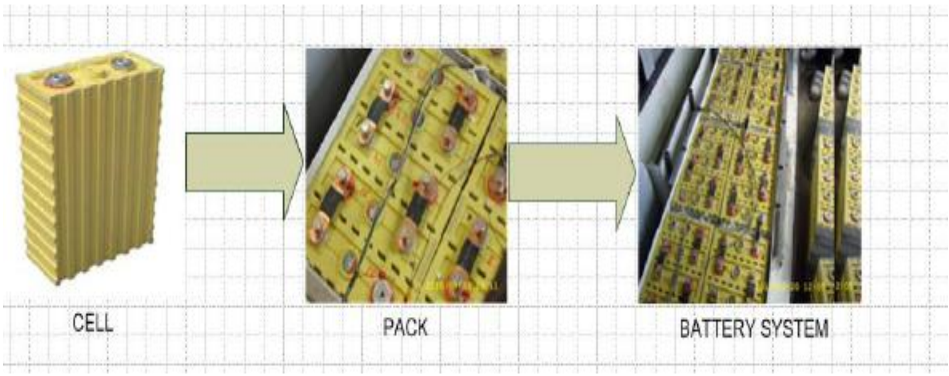


Figure 4.4: Battery Package System.

The batteries need to accessories such as straps, bolts, screws to fix the batteries when the cells are assembled in series.(see Figure 4.5)

Figure 4.5: Accessories.

Batteries are placed at the bottom of the seat (see Figure 4.6) and they do not have the cooling system. The cooling system can be developed after this period but the battery temperature range is sufficient to compensate the situation.

Figure 4.6 Battery Cells under Seats.

Battery packs are grouped with respect to internal resistances because the charge problems can occur if there is a big difference between grouped cells with each other. It is not normal if any cell voltage in one pack is 1 volt lower than others. Regularly there can be 1 Volt difference in voltage among cells of the packs. The Figure 4.7 shows that the voltage difference examples about the cells.

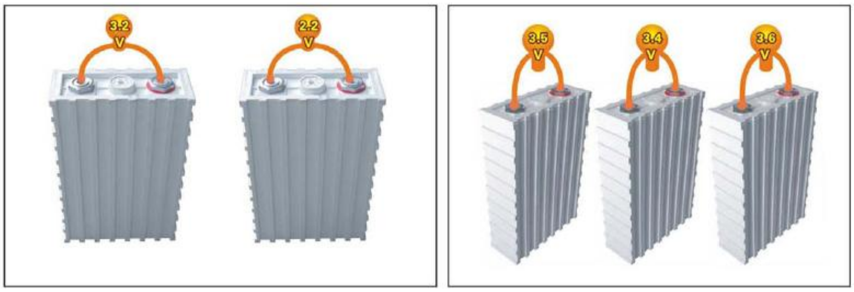


Figure 4.7: View of Cell Voltages.

Conclusively, battery cells are grouped on vehicle according to internal resistance of cell packs. If cells of packs have big internal resistance between each other, the charge and discharge problems can be observed; thus, the cells are grouped against internal resistance.

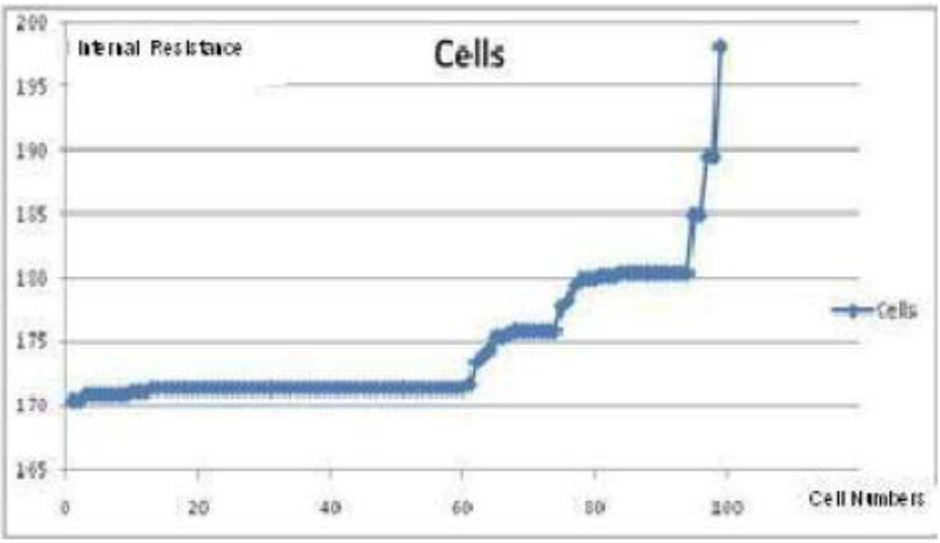


Figure 4.8: Internal Resistances of Battery Cells.

In this application, there are 100 cells and they are packed in 20 groups; namely, each five cells set up one pack. Figure 4.8 shows the internal resistances and number of cells. The batteries are packed with respect to their internal resistances. Internal resistance of each cell in one pack must be near to each other because the discharge life will increase with this arrangement. If internal resistances in one battery packs have big differences, the situation can damage the battery packs when charging.

In addition to them, when packaging the cells, the cells are not made short circuit with touching anode and cathode. Moreover, the new battery is not discharged. The situations are explained in Figure 4.9.

Figure 4.9: Short Circuit & Discharge Problems on Cells.

4.6 BMS System

4.6.1 System Structure

BMS is the battery management system which controls the battery packs. The important criteria's to choose the BMS system is voltage, current values and number of cells that it controls. The other criteria is the report capacity which means the properties of cells that the BMS system can record. In electric minibus application, the BMS should record all cells state of charge values, temperatures, voltage and current values. This process can be made not only in charge situation but also discharge situation.

The Battery Management System in Electric Minibus Application consists of a host controller, modules for voltage, temperature sampling and current sampling, colorful led screen with touch panel.

Host is the main controller for the battery cells, CH is the current module which protect system from hall effects, VT is the voltage and temperature modules and the display is the screen to see the results.(see Figure 4.10)

The product has a structure as shown in Figure 4.10.

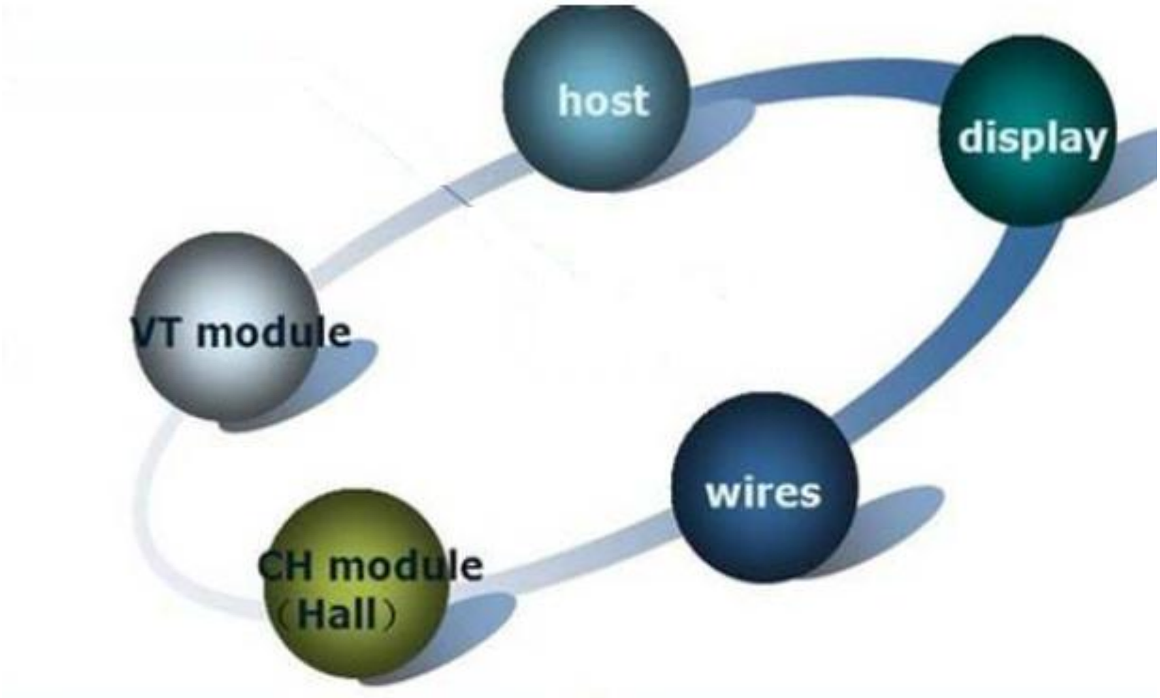


Figure 4.10: BMS System Structure.

The components of the system which is built on the vehicle is shown in Figure 4.11.

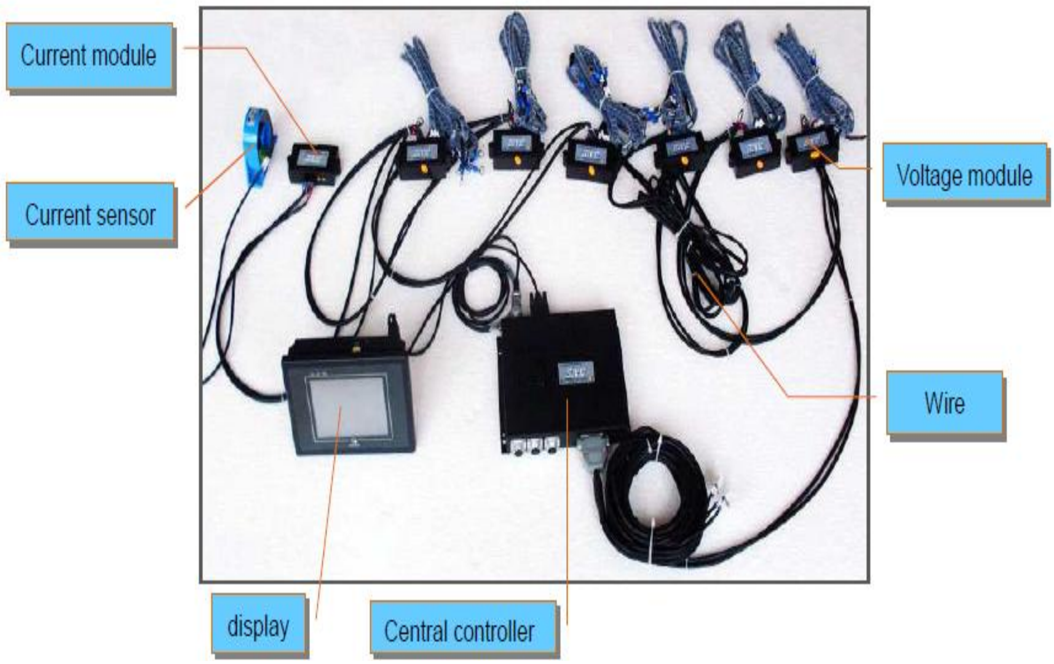


Figure 4.11: BMS System Equipments.

The host master consists of display and central controller. The first page on Screen displays total voltage and current of the pack, remaining power that the system have, maximum and minimum voltage cells and its values, state of charge value, highest and lowest cells and their numbers, maximum temperature.

The all sample data can be screened for each cells such as voltage, temperature, capacity. The system running parameters can be set with this screen. The running parameters includes the choice of number of batteries and their sampling modules, upper and lower limit voltage alarm of cells, temperature upper limit alarm, current upper limit alarm, voltage difference upper limit alarm, SOC initial value, rated capacity, system clock, storage electrical quantity calibration coefficient, and so on.[12]

There is a modularization structure which collects the system voltage and temperature. It manages 10 battery cells and 1 road temperature.

4.6.2 Main Controller of BMS

The host provides the CAN Bus which is used for connection with the vehicle controller. The main controller of BMS has 7 connection on the hardware which is explained in Figure 4.12 that are about supply voltage, CAN interface, RS connection and USB interface. This main controller enables to store all the data.

Figure 4.12: BMS Main Controller.

In Figure 4.12,“1” is the supply voltage connection which is 12 volt and enabled by batteries.“2” is additional 7 pin outs. “3” is CAN communication interface which is 4 pin. “4” is the data collection modules communication interface and beep warns output.“5” is dc output voltage which is 3 pin and it is supplied by 12 volt, “6” is RS 422 connection to touch display communication interface, and finally “7” is USB interface which enables to download the data to host computer.[12]

The main controller of BMS is placed near to wheel drive and the screen is placed above the BMS host controller.(see Figure 4.13)

Figure 4.13: BMS Main Controller & Screen Place.

4.6.3 Current and Voltage Modules

Voltage modules are used to collect the voltage data. Each module can control 10 cells which mean for electric minibus two packs, and it can also control the temperature with one probe for these ten cells. There is one current module and this module has Hall effects sensor to protect the signal from hall signal effects. In Figure 4.14 the voltage module can be seen obviously.

Figure 4.14: Voltage Module.

Voltage Module includes 14 pin for battery cell information, 6 pin for data communication, DIP switch and Communication indicator. DIP switch shows the module type which can be voltage or current module. The Communication indicator shows the module number that the cells are controlled for voltage and current.

DIP and Communication Indicator can be explained in details. The main logic can be shown with the chart in Figure 4.15.

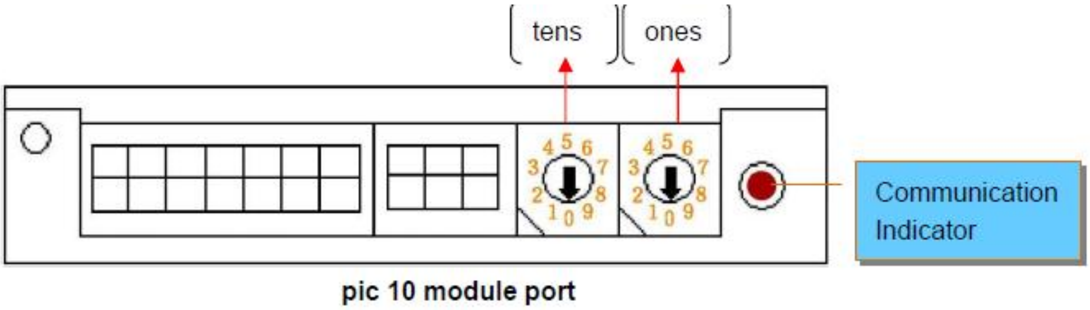


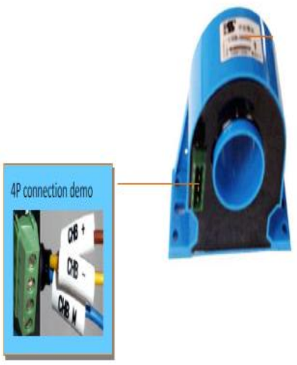
Figure 4.15: Voltage Module Indicators.

In minibus application, there are ten voltage modules. According to direction of above Figure 4.15 from left to right settings for each module is: 00, 01, 02, 03, 04, 05, 06, 07, 08, 09. Tens in voltage module is 0 and the 10 modules are described with number between 0 to 9. For the current module, the setting is 10.”Tens” means 1 which defines the current module and “ones” has a meaning which shows there is only one module.

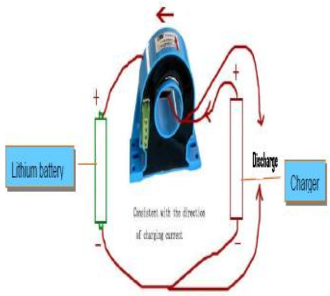
The current module has a different hardware structure with respect to pin outs. There is 4P pin out which shows collection current data. Next, there is a 6P pin out which enables to record data with communication wire. It has also DIP Switch and Communication Indicator. The current module is shown in Figure 4.16.

Figure 4.16: Current Module.

4P pin outs includes only 3 pin connection and it includes positive, negative ends and data transfer connections. The 4P connection is used to transfer information to Hall Effect sensor. Hall Effect sensor and its position in the vehicle which is in the start circuit are shown in Figure 4.17.



Hall Effect Sensor



Hall Effect Sensor on Vehicle

Sensor @ Start Circuit

Figure 4.17: Hall Effect Sensor & Its Principle.

Hall Effect sensor should be placed between battery and electric motor which is at the start circuit and also charge wires are placed with the opposite path of charge situation.

4.6.4 Color Touch Screen

Color Touch Display is supplied by 12 V power input and the data communication is enabled by DB9; namely, 9 pin connector. The hardware is shown in Figure 4.18. The screen is placed at the top of the vehicle overall.

Figure 4.18: Display Screen.

The main page of the display includes the total voltage and current data, remaining power of battery, maximum and minimum voltage of the cell which has the biggest value, and the cell temperature which is the biggest one. Date & Clock information and menu is additional cases. The main page is in Figure 4.19.

Figure 4.19: Display Screen Main Page and Menu.

In menu content, SET part is to set up the necessary data when the system is used at first time. It includes battery system information and two system parts. Battery system is used to set up battery quantity and temperature.[12] The Set part and the Battery system part is shown in Figure 4.20.

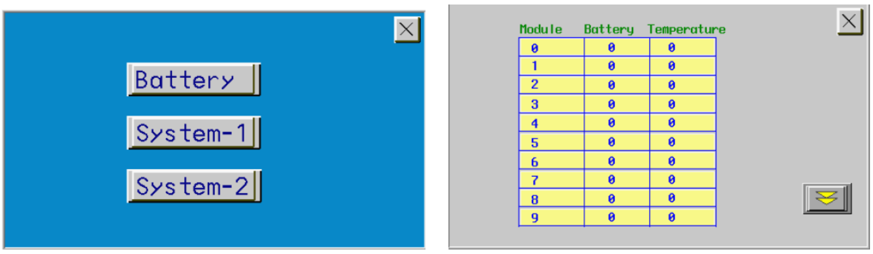


Figure 4.20: Set Button & Battery Part Screen.

Battery part screen includes the system information about module number, battery number and the cell temperature value. Module number can be between 0 and 9 because there are ten modules to manage the system and they are set from 0 to 9.

Namely, Module column is module address. Battery column is battery quantity and they are always 10 because the battery module can control 10 batteries which are two packs and there are also ten module. Temperature module can be O or 1. 0 is no information about it, 1 is the meaning of taking the information from the system.

The system 1 and system 2 are shown in Figure 4.21**.**

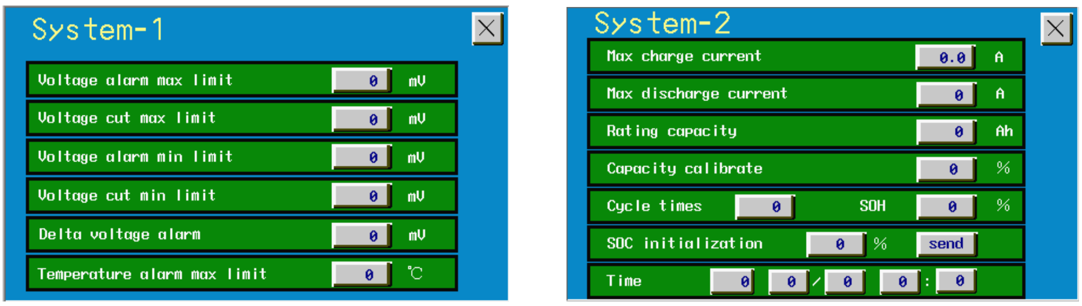


Figure 4.21: System Information.

In System 1, “voltage alarm maximum limit” is the value of voltage which enables battery management system to be warned and control charger to balance charging process when one of the cells reaches this value. “Voltage cut max limit” provides with warning and stopping of the charging when the one of cells reaches this value, and it only shut off the power. Minimum limits to alarm and cut has the same logical approach. Delta Voltage alarm is the value of difference for highest alarm voltage and lowest alarm voltage. Temperature alarm maximum limit is warning the controller when one of cells’ temperature value reaches the higher value.

In Electric minibus application, the maximum voltage alarm limit is 4.25 volt and voltage cut max. limit is 4 volt. When voltage alarm min. limit is 2.5 volt, cut limit for minimum is 2.4 volt and vice versa. Delta voltage alarm is 2.7 volt comes from the difference of highest and lowest values. Moreover, temperature limit is the limit for LiFePo4 battery limit which is 85 C degree.

In System 2, “maximum charge current” is output maximum current value. “Maximum discharge current” is allowed by BMS and if it is more than this limit, the system is warned. “Rating Capacity” is for single cell and it is consistent with the SOC. “Capacity Calibrate” notices current sensor fix direction. “Cycle time” is times of charge and discharge. “SOH” is the state of health and it is about health status of battery pack. “SOC initialization” is sent after first charging is done. “Time” is about saving the data of the system.

In Figure 4.19, the charge button in menu part enables to see the state of charge and temperature information on the screen as Figure 4.22.

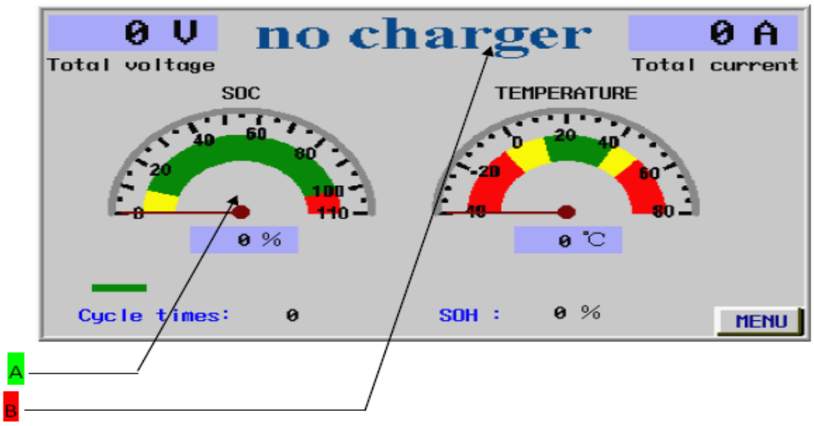


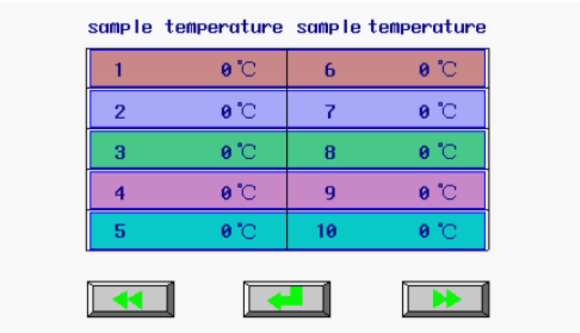
Figure 4.22: Charge Panel.

"Green A" is State of Charge (SOC) status. When the battery cells are charged, the bar of system scrolls. Static bar value shows the State of charge value.

"Red B" defines the charger status of indicator. If the writing of "Red B" part is "no charging", charger is not connected. If the writing is "ready", the system is ready to charge. Moreover, if the writing is "charging", the system is charging. Next, if the writing is "stop", the charging should stop. Return means that the user can go to back to homepage.

The temperature and state of charge has the monitor system in this page.

In Figure 4.19, The "First" button of menu part enables to turn the homepage of the screen. In menu bar, the "temp" link provides with monitoring the sample cells and their temperature values. These are module based temperature relation. The screen of it is in Figure 4.23.



Module Based Temperature Values

Temperature Values of Each Cells

Figure 4.23: Temperature Values on Screen.

In Figure 4.19, The "more" button shows the all cells temperature values that enables to understand which cell has temperature problem and the screen is seen in Figure 4.23.

In addition to them, if the system controller cannot communicate with the cells and modules, the system provides scroll word and alarming.

Battery Management System has a control algorithm like in Figure 4.24**.**

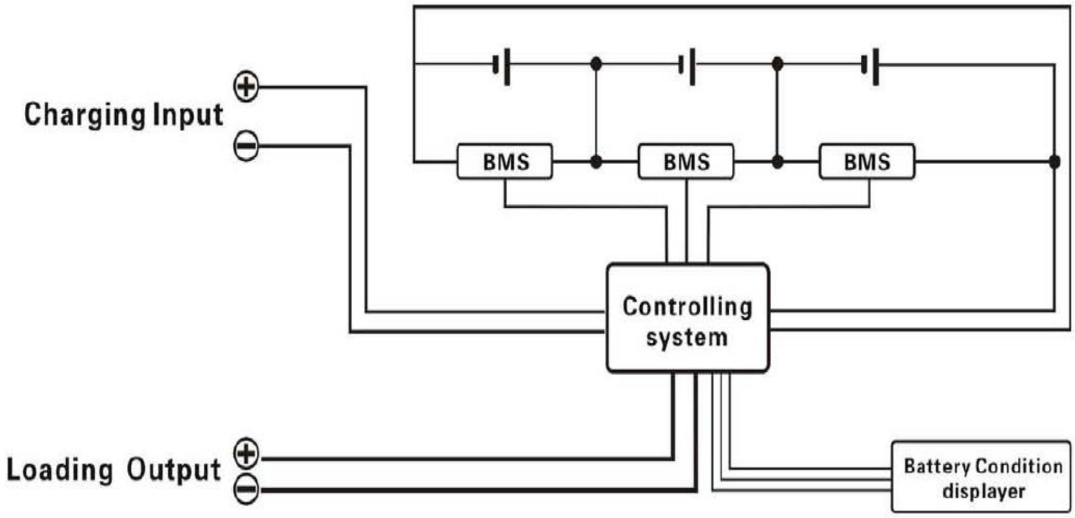


Figure 4.24: Control System & BMS Relation.

The charging input in the system works when the batteries are charged and it is associated with controlling system. Controlling system controls the BMS systems. Display is screen to see the situation on the system. Loading output is sent when the system works. Loading output is the power to move the vehicle. The system can have series connection or parallel. In Electric minibus application, the cells are in series and the BMS modules are also series.BMS system has an electronic circuit to prevent cells from damage caused by overcharging and over discharging so they are monitored. BMS system in electric minibus application is unique. There can be more BMS system if necessary like in Figure 4.24. If there are more BMS system, the necessary circuits are added to the system.

The lithium iron phosphate batteries are charged by fast mode because cathode activity is sintered by fluoride and thulium mixture. Anode activity is enabled by nano carbolic fiber and handmade graphite, which can maintain its original molecule and it, can endure impact when it is charged with big current.

5. CONTROL DESIGN AND COMMUNICATION

The vehicle control design of electric minibus is processed by Microautobox D-space 1401 and the Control Area Network (CAN) communication is used to communicate the control algorithms with each other.

This part is investigated in details in two parts:

- Control Part
- Communication Part

5.1 Control Part

The control design part includes basic application term definitions and examples, the information about the vehicle controller, the vehicle control design which is embedded to the vehicle controller, all applications on electric minibus about control process.

Vehicle Controller is Microautobox D-space 1401 is shown in Figure 5.1.

Figure 5.1: Vehicle Controller.

First of All, the vehicle control and its design include basic terms. If the application engineer cannot understand these terms exactly, there can be main problems at the soft control design and embedded control design. These terms are Analogue Digital Converter (ADC), Digital Analogue Converter (DAC), DAQ system, digital signal processor (DSP), Digital Output (DO).

ADC is the term which enables the analog input to convert digital output. For instance in vehicle, the gas pedal is touched by driver which is analog process. This is rotational motion. The potentiometer which is attached to gas pedal converts this rotational motion to rotational angle and then converts this angle to voltage value between 0 to 5V. It is sent to Vehicle Controller. ADC parts of the controller converts this voltage value to digital output which has a range between 0 and 1.As a result, the ADC part can be used.

DAC provide the controller with completing DAQ system. With the same example of ADC, the potentiometer, which is attached to gas pedal, has three pin outs which are ground, ADC which has explained and DAC. The potentiometer has a voltage difference between ground and DAC so DAC can be described as the source of this DAQ system which enables the voltage supply.

DSP is the digital signal processor which is vehicle controller in this system.

DAQ system includes the ADC, DAC, DSP and the process flow shown in Figure 5.2 enables the signal processing of the control system. In Figure 5.2, the same example about gas pedal is summarized as a DAQ system.

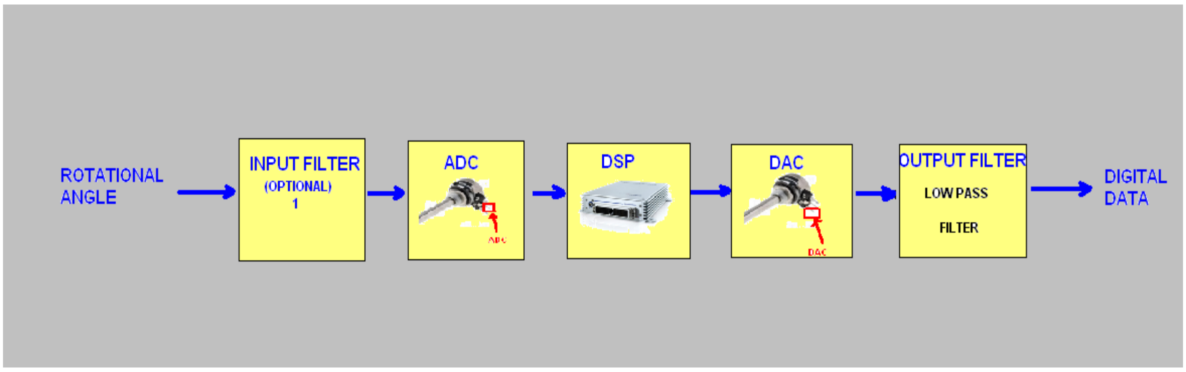


Figure 5.2 : DAQ System.

As it is shown in Figure 5.2, the DAQ system enables the vehicle to use the data correctly. The filters are important to protect the systems from inrush effects. ADC sends the necessary rotational motion to the DSP after converting it to the voltage value, and then DSP processes the digital output. By the way, the DAC enables the voltage difference to the system. The low pass filter as an output filter is used and the reason will be explained in Control Algorithm part.

The Microautobox pin outs configuration includes the ADC, DAC, DO and all types of signals.

Another example is about DI which defines the break process. The DI signal is taking from brake pedal and goes to DI value on Simulink design with autobox controller and it is used in control strategy. General summary about the process can be defined as Figure 5.3.

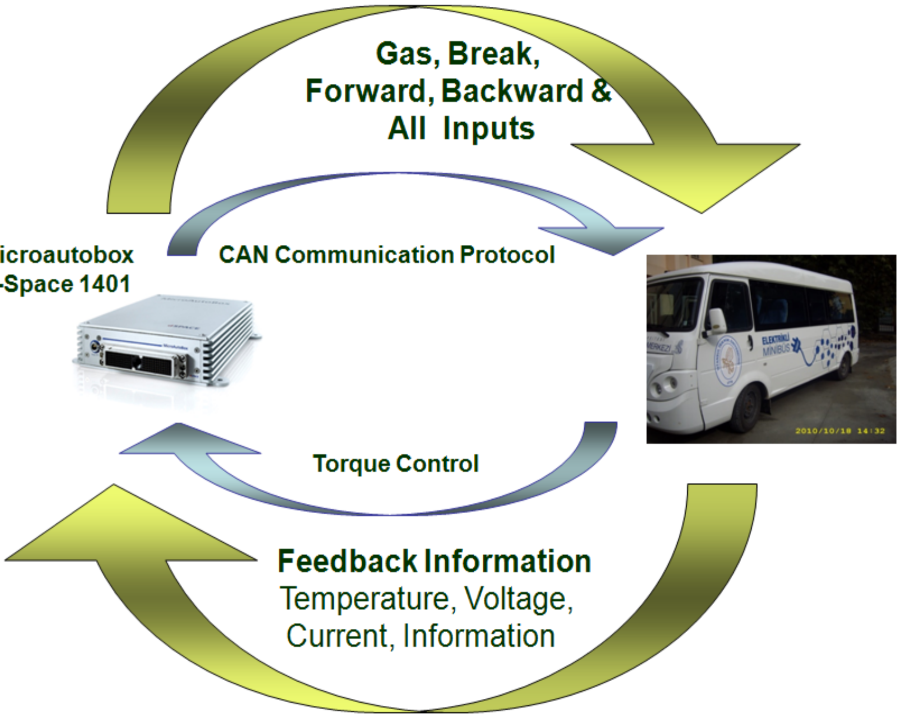


Figure 5.3: Control Design Summary.

5.1.1 Embedded Control Design of Electric Minibus

Vehicle controller of electric minibus is Microautobox D-space which requires power supply within the range of 6 Vdc to 40 Vdc; so12 Vdc gel batteries are used.[13] The vehicle controller design process can be evaluated in two parts which are vehicle control such as forward, backward, starting the movement, cutting off the voltage and CAN communication which is explained at the next part.

The logical approach for the embedded control design is explained in Figure 5.4.

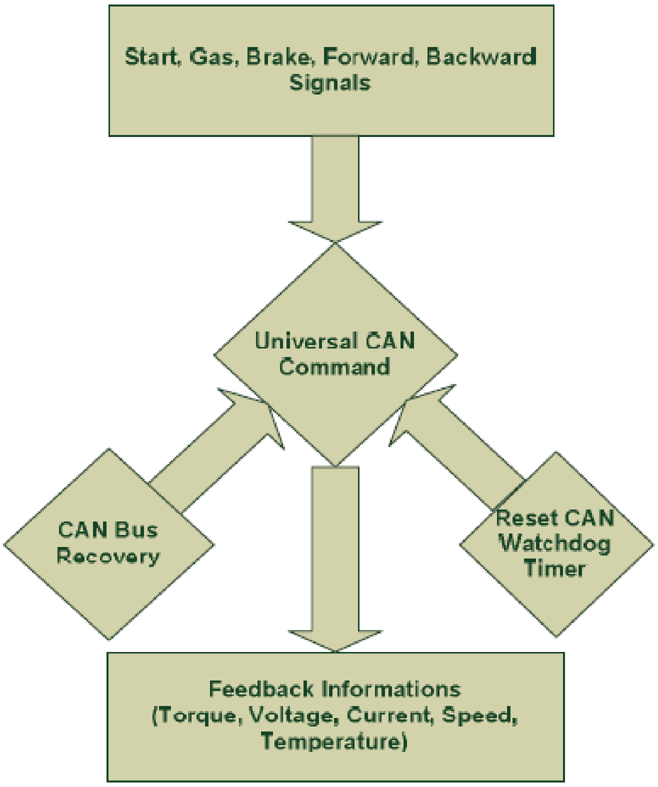


Figure 5.4 : Main Logic of Embedded Design.

In Figure 5.4, the basic operators such as start, gas, forward, backward signals are sent to CAN Command, then the necessary feedback information can be taken from the vehicle. The feedback information includes torque, voltage, temperature and the other information. The CAN problems can be occurred and these problems are compensated by CAN Bus recovery module and Reset CAN watchdog timer.

In details, the embedded design can be investigated in four parts. These are;

- Basic Operators
- Universal Command Information
- Protection from Communication Problems
- Feedback Information on Design

5.1.1.1 Basic Operators

The basic operators are start, forward, backward, brake, gas information. These information in design is shown in Figure 5.5.

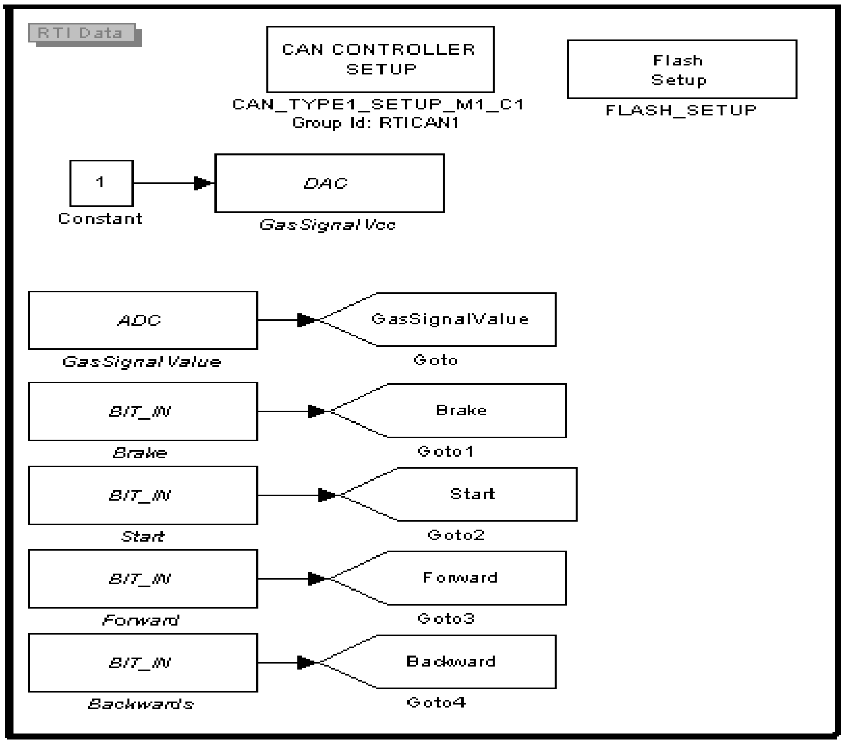


Figure 5.5 : Basic Operators in Embedded Design.

In Figure 5.5, RTI Data means this is the real time process. The DAC is the part of DAQ system of gas pedal and gives the voltage between 0 to 4.5 volt. The ADC is the gas signal value which converts voltage value which is 0 to 5V, to digital values which is between 0 to 1. Brake is the DI in the system and the value of DI is only 0 or 1. If the brake value is "1" in which the driver touch the brake pedal, the signal is sent. If the brake value is 0 where the gas signal value is sent, no information goes to universal command as a break signal. The important point in this process is the difference of DI and DAC. DAC value can be between 0 and 1 but the DI value can be only 1 or only 0. Forward and Backward buttons on the vehicle are in Figure 5.6.

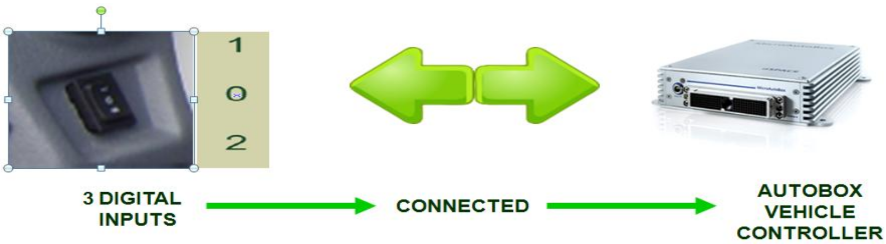


Figure 5.6 : Forward Backward Buttons.

In Figure 5.5, the start button is used to work the vehicle when the key is turn on. In addition to them, there are two set ups for the CAN and MEMORY. Can set up includes 4 parts which are Can Unit Data, Data file support, Options and File Type. The Can Unit is shown in Figure 5.7.

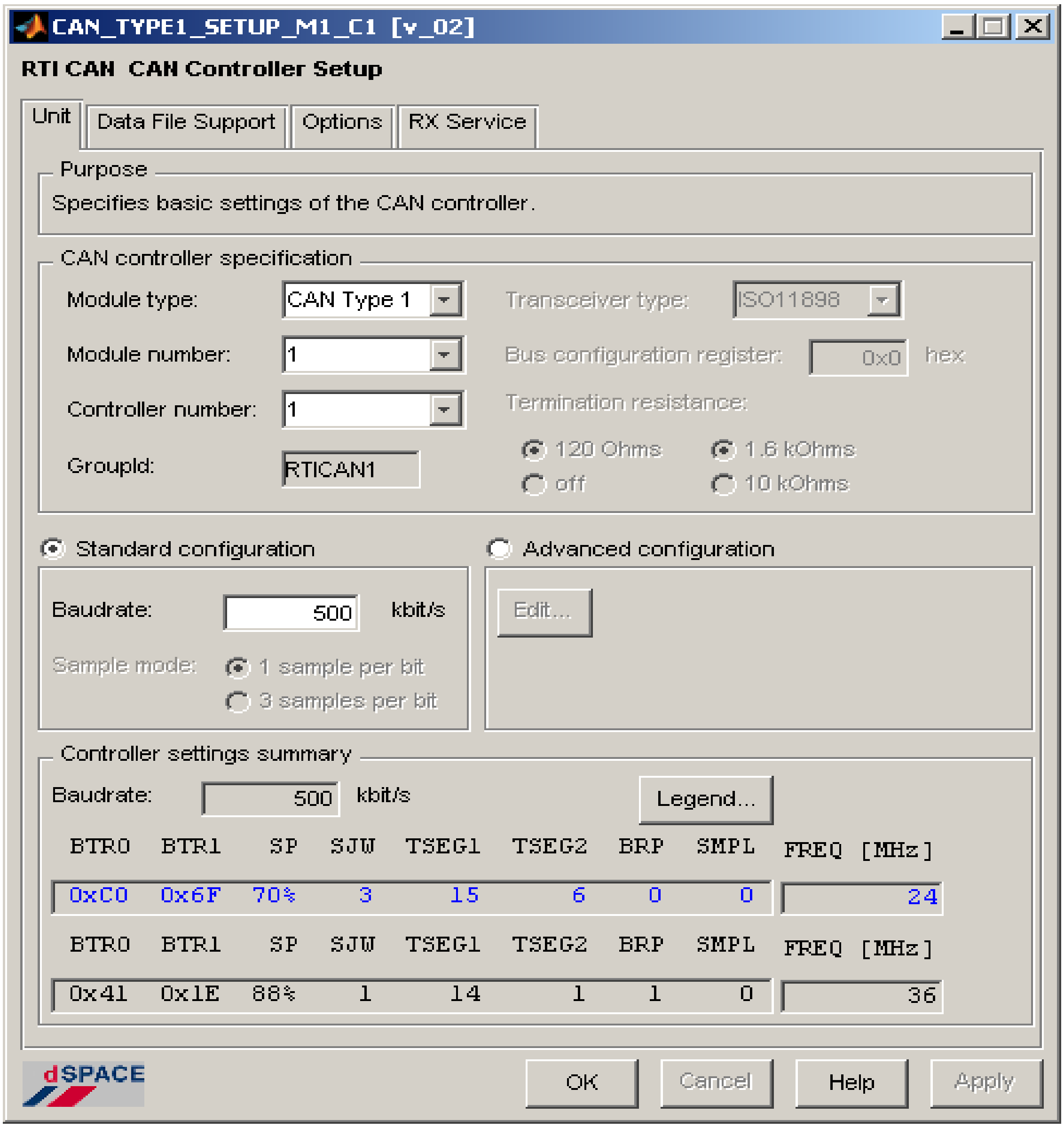


Figure 5.7 : CAN Set Up Unit.

CAN Set up Unit include module type number and controller number which are related to Simulink address so they are chosen the same with Electric Motor Parameters. In electric minibus, the Module type is 1, module number and controller is 1 as an address. The baud rate which is also chosen the same with Electric Motor Specifications is 500 kbit/sec.[13]

The other part for CAN Set Up is Data File Support part which enables to use data file. This data file is provided by electric motor software. The electric minibus data file is 11 bit little Endian data file is shown in Figure 5.8.

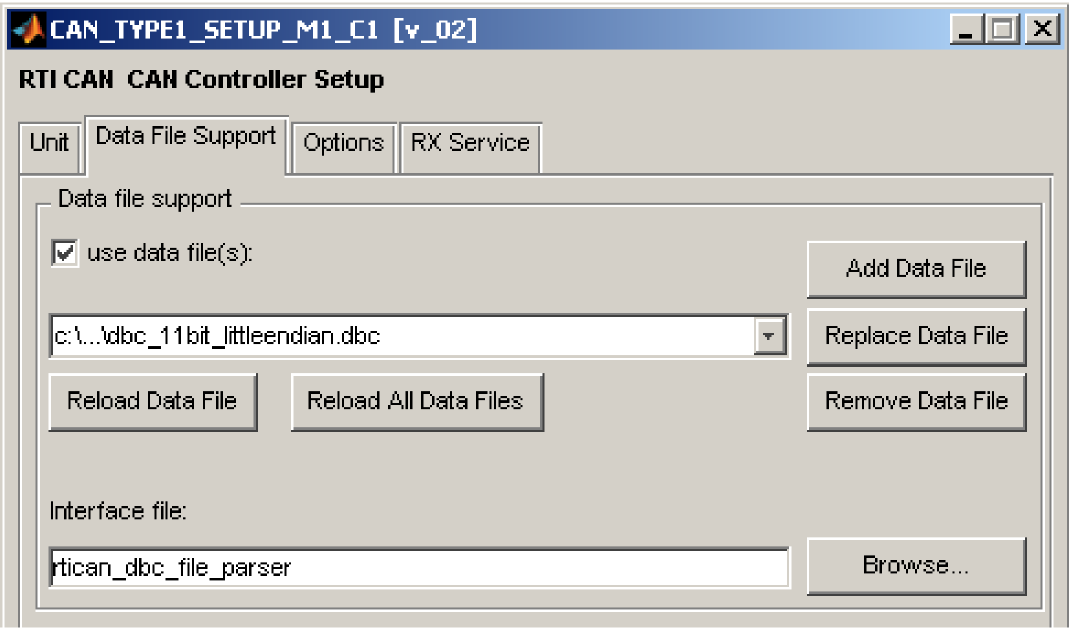


Figure 5.8 : Data File Support.

Moreover, the options part in CAN Set Up includes data information type. (see Figure 5.9) Data information is derived from CAN Signal specification in Electric Minibus Application. The message model is extended so the multiple message access mode is activated.

At the last section in CAN Set Up is RX Service which defines the received message types are standard or extended. Standard type message is shorter message than extended one. The usage can be changed action to action in control process.(See Figure 5.10)

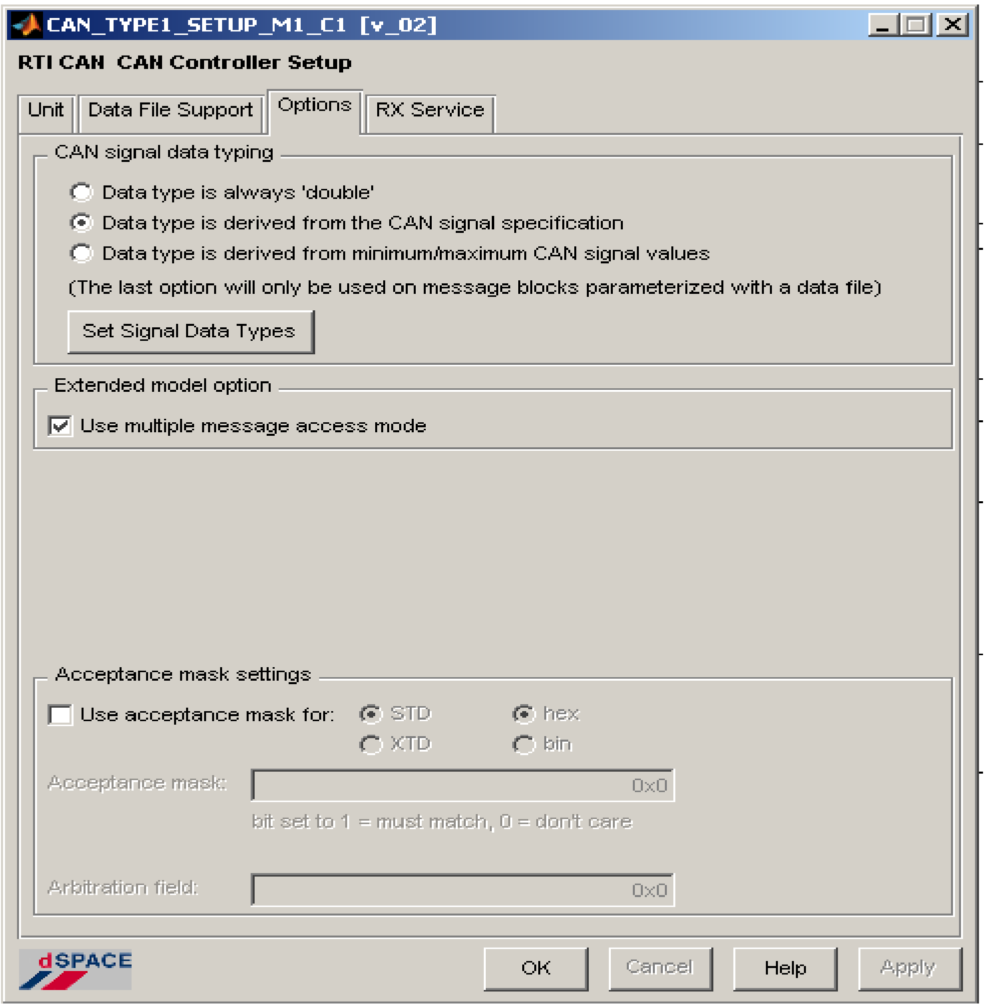


Figure 5.9 : Options in CAN Set Up.

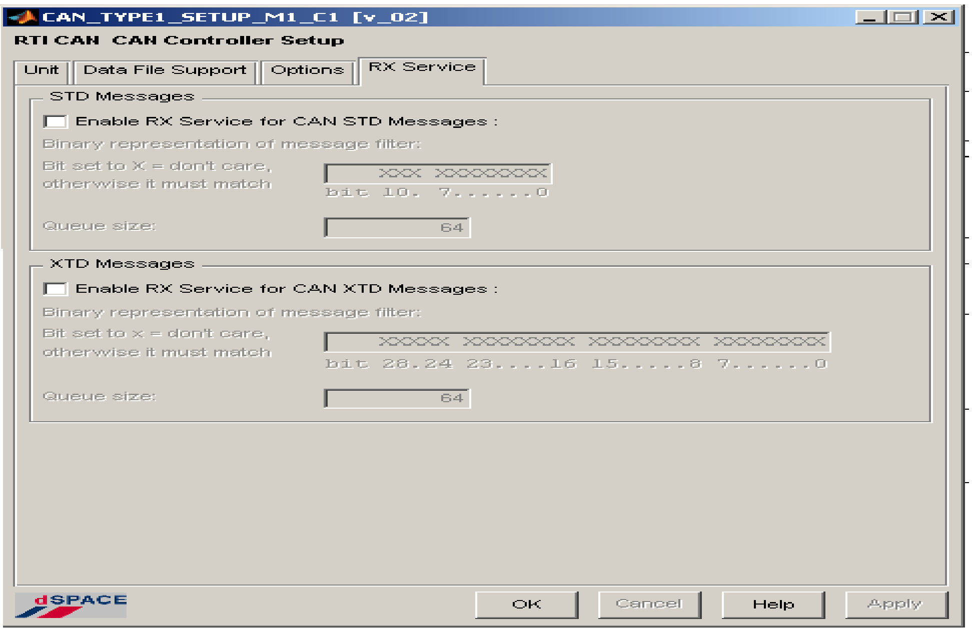


Figure 5.10 : RX Service of CAN Set Up.

In Figure 5.5, the other Set Up is about data Flash Set Up which enables driver to record the data. The Data can be loaded to flight recorder or permanent recorder. The flight recorder has 13 megabyte memories. After recording data, it can be cleaned. This block in Microautobox is shown in Fig. 5.11.

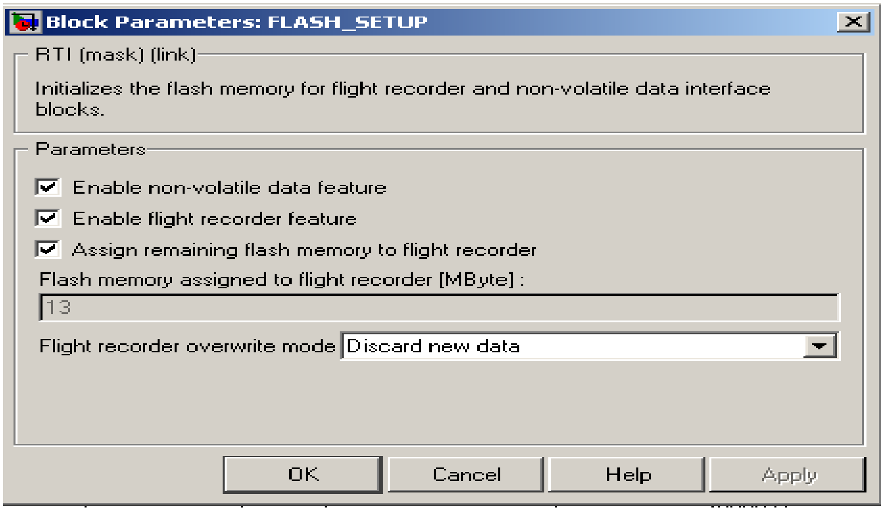


Figure 5.11 : Flash Set-Up.

5.1.1.2 Universal Command Information

The Universal CAN Command is the main process of the vehicle movement. The command includes the information about drive mode, which is Torque mode in electric minibus. Information of vehicle direction, which is forward if the command block, does not send the backward signal. Moreover, “Universal Command Enabled” part in command defines the combination of start and direction information. In addition to them, The “Command Request” is the main process, which takes the information from gas or brake pedal. There are the speed limits to restrict the moment of electric motor. (see Figure 5.12) Request information defines the gas signal and brake signal. The brake signal takes the information from brake pedal. The gas signal is multiplied with the experimental gain, which is found by the experiments with the electric minibus. There is a transfer function defines the low pass filter which protects the electric motor from inrush current. The forward and backward speed limits can be at the range of -1000 to 3000 rpm. (see Figure 5.12) The blocks of “write the flight recorder”, “rate transition” and “data type conversion “ record the data into memory. (see Figure 5.12)

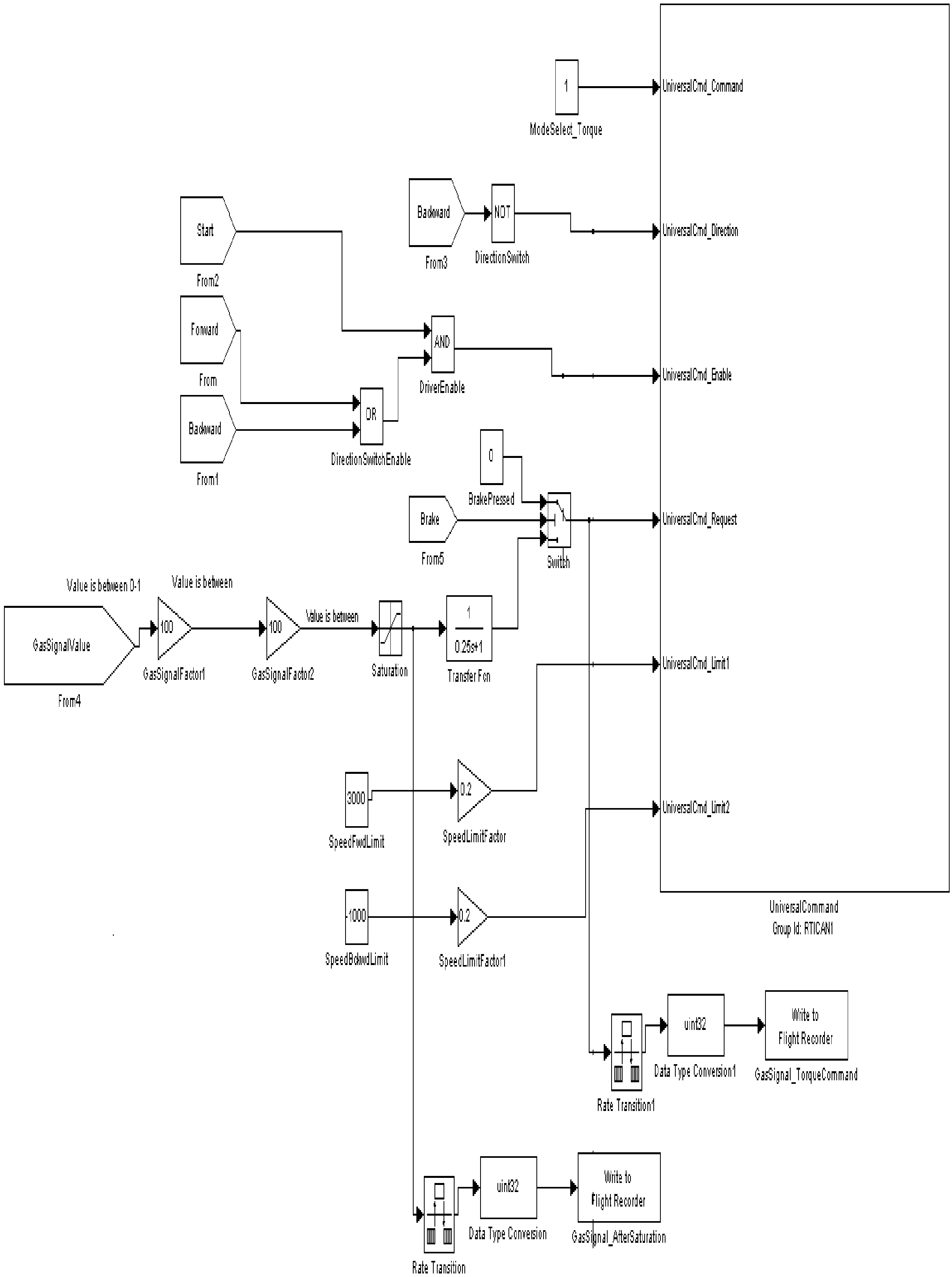


Figure 5.12 : Universal Command on Design.

5.1.1.3 Protection from Communication Problems

The protection from the CAN Problem is enabled by Reset CAN watchdog timer and CAN Bus Recovery. “Reset CAN Watchdog timer “protects the CAN communication at the electric motor side. It includes three main items, which are reset command, reset timer and reset error values. “CAN Bus Recovery Module” protects the communication at the vehicle controller side. Considering everything, there can be communication problems at the two sides so these modules are used for them. The protection is shown in Figure 5.13 as a Simulink design which is embedded to vehicle controller.

5.1.1.4 Feedback Information on Design

Accurate feedback information’s on design are torque, voltage, current and speed for electric minibus. Temperature of electric motor can also be recorded as shown in Figure 5.14.

The feedback information is important so that taking preventions if the problems about temperature and other parameters can occur. These data are recorded with the “Data Flight Recorder” module which has 13 MB memory. The data is used as Unit 32 type data which is converted by “Data Type Conversion” Module. The blocks Rate transitions enables the data usage with low memory and fast response.

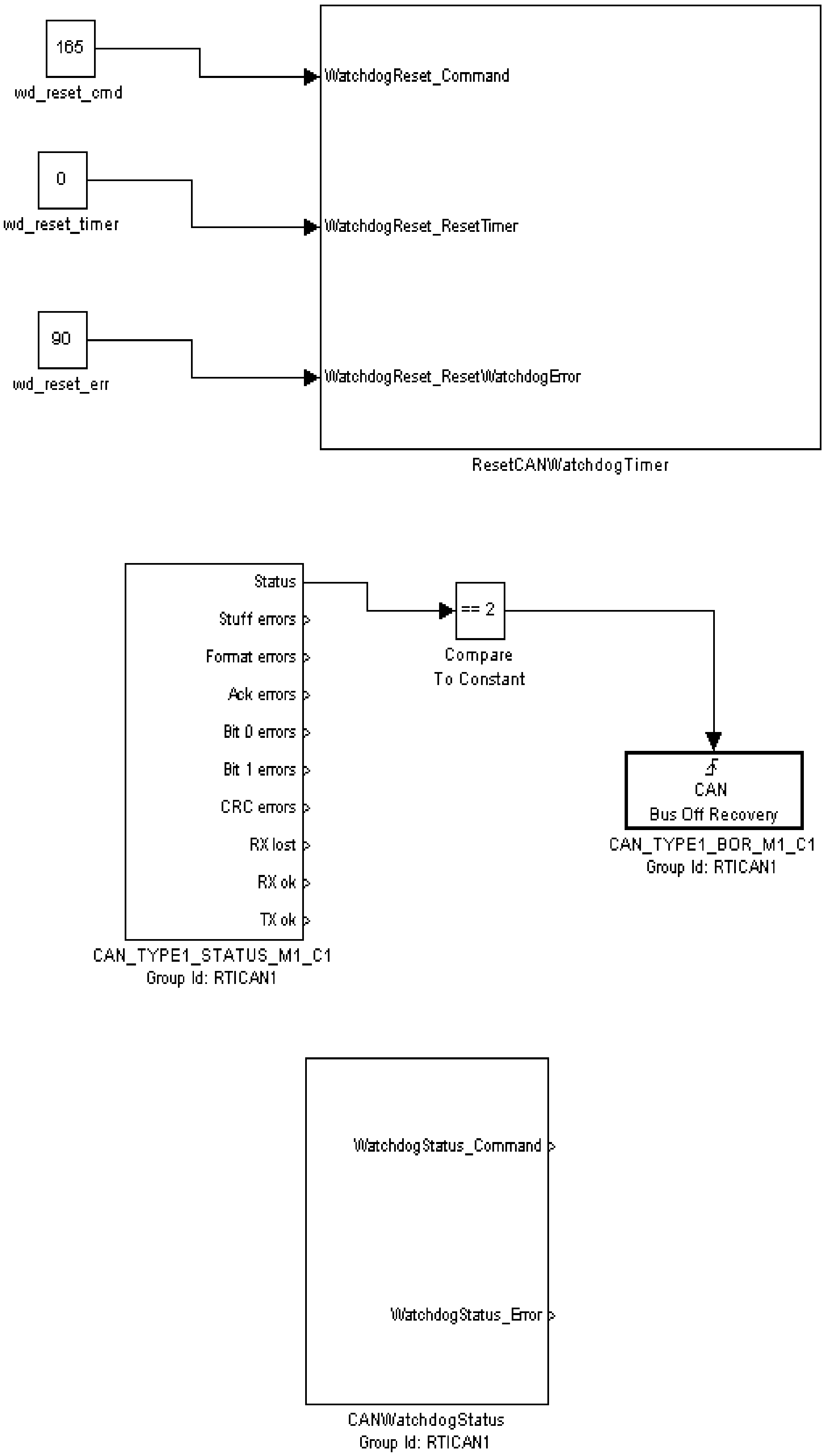


Figure 5.13 : Reset Communication Blocks on Embedded Design

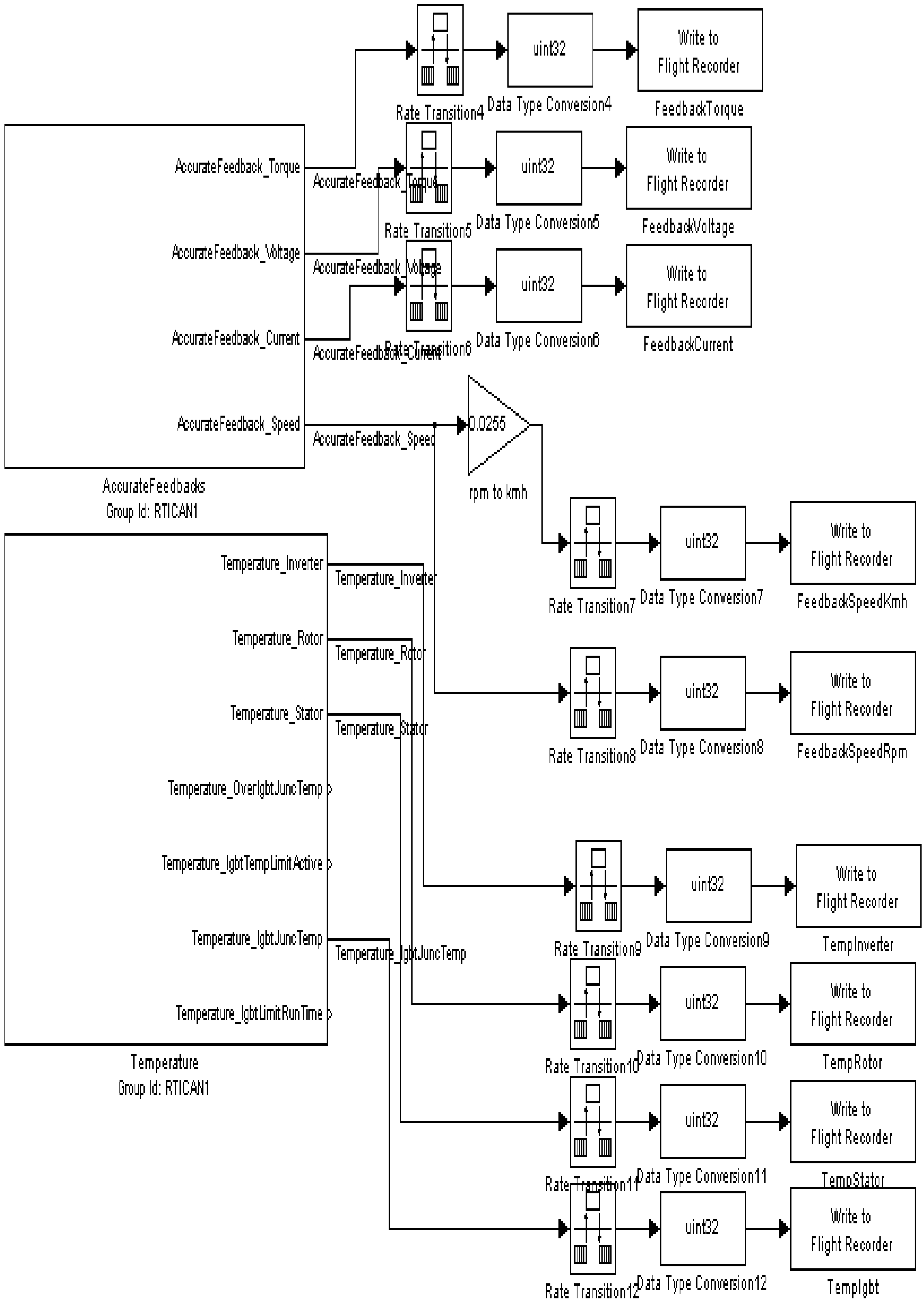


Figure 5.14 : Feedback Information on Control Design

5.2 Communication Part

The vehicle communication is CAN which is control area network. CAN is a vehicle bus (communication network) standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer. CAN is a message based protocol designed specifically automotive application. It is also called as multi master broad coast serial bus standard for connecting electronic control units. Sensors, actuators, control devices can be connected directly to the bus, but through a host processor and CAN controller.

CAN system can command three modes of operation; these are :

- Torque Control/Speed Limit
- Speed Control/Torque Limit
- Voltage Control/Current Limit

"Universal Command" commands all three modes. The electric minibus has a mode of operation as Torque Control /Speed Limit. There is a switch mode called "Dynamically Switching Control Modes" enables to switch between these three control modes.

The CAN protocol for electric minibus has two user-selectable option for either 29-bit or 11-bit identifiers. The protocol data unit for all proprietary messages is 239 (OxEF). The protocol also has the highest priority 0 and lowest priority 7.[8]

The two types of identifiers 29 bit and 11 bit have the following fields in Figure 5.15.

	Priority	0	0	PDU Format (PF)	PDU Specific (PS)	Source Address (SA)
Bit 31-29	*Bit 28-26*	*25*	*24*	*Bits 23-16*	*Bits 15-8*	*Bits 7-0*

Source Address (SA)	*Message Direction*	Priority
Bits 10-4	*Bit 3*	*Bits 2-0*

Figure 5.15: Identifier Fields for 29 bit & 11 Bit

In electric minibus, the 11 bit identifier is used so only the source address (SA) and priority are defined and the message direction is used in embedded design. In addition to them, the 29 bit identifier includes protocol data unit (PDU) as format & specific and Source address. When the priority bit in 11 bit identifier is the first two bits, it is between 26 and 28 bits in 29 bit identifier and vice versa.

If using 11 bit identifiers, the message is sent like “0xrrp” where “rr” represents the UQM address, p represents priority.

In electric minibus application, the Watchdog timer block (see Figure 5.13) includes watchdog reset command, reset timer and watchdog error. Reset timer should be 1 because 0 describes inactive and 1 describes active. For watchdog command, the CAN manual refers the data range as OXA5 as shown in Table 5.1.

Table 5.1: Reset CAN Watchdog Error & Timer Properties

RESET CAN WATCHDOG ERROR	
Use:	Control
Data Length:	1 byte
Resolution:	N/A
Data Range:	0x5A
Type:	Command

RESET CAN WATCHDOG TIMER	
Use:	Control
Data Length:	1 byte
Resolution:	N/A
Data Range:	0xA5
Type:	Command

0X5A data range enables to have a constant value of 90 in decimal system so the 90 is entered in Simulink constant block and related with error block(see Figure 4.13)

Another example about the message in hexadecimal number is watchdog timer which is 0XA5 refers to 165 and it is produced as a constant in Simulink in embedded control design. (See Figure 5.13)

The universal command takes the command types as hexadecimal. The torque control is 0X01, speed control is 0X02, and voltage control is 0X03. The electric minibus system is 0X01 so the decimal number is 1 and the constant block is used in Simulink with the value 1. (See Figure 5.12) The byte following the command byte includes bits. It is used for enable command which is sent (bit 4, in which LSB is bit 0) and direction control (bit 3, in which LSB is bit 0). The bit 4 is set to zero, system is disabled and the torque value is zero so it controls the zero torque. If bit 4 is set to one, system is enabled and the requested torque is controlled.

Bit 3 is direction bit. When bit 3 is set to 1, the motor can go forward. If the bit 3 is set to 0, electric motor goes to backward.

6. CONCLUSION AND RECOMMENDATIONS

The major purpose of this research was to built the first prototype of full electric minibus in Turkey. This electric minibus has been designed and constructed. The research and development of the vehicle will continue as:

- Adding ultra capacitors to the vehicle high voltage line to make regenerative breaking more efficient.
- Designing the smart control processes to improve active safety algorithms.
- Energy management system strategy will be developed to make the electrification more efficient.
- Performance and efficiency of selected vehicle components will be increased with regular maintenance.
- Adding of solar panels to make the vehicle as hybrid structure to increase energy storage.

Taking everything into consideration, this project enables Istanbul Technical University to have a good marketing in this scientific area not only in Turkish media with announcing on all channels between the dates 19 to 21 October 2010 but also in Scientific Area all over the world with the presentation in IEEE conferences which is IEEE ICM 2011 (13-15 April, 2011). This conference is international conference of Mechatronic which is one of the serious enterprises and this project is presented in this conference as a Mechatronic research on vehicle application.

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APPENDICES

APPENDIX 1 : Electric Motor Hand Control Electric Interface

APPENDIX 2 : Inverter 2D Cad Data

APPENDIX 3 : Electric Schematic of Electric Motor Control Circuit

APPENDIX 4 : ITU Maslak Campus Service Map

APPENDIX 5 : Battery 2D Cad Data

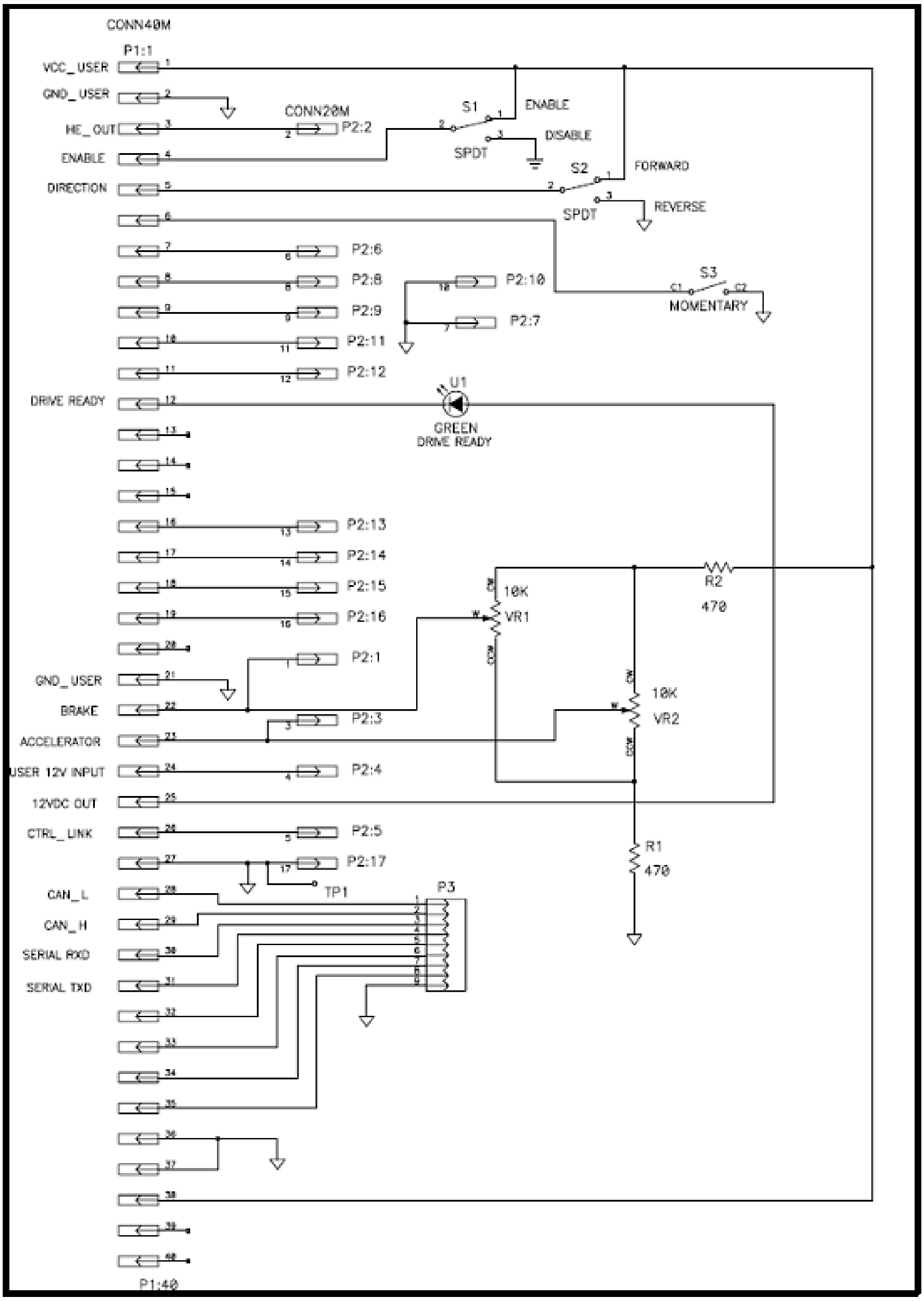
APPENDIX 6 : BMS System Principle

APPENDIX 7 : MATLAB CODES OF BREAKING ENERGY @ CONDITIONS: MAX.GRADIENT-FULL WEIGHT OFVEHICLE CONSTANT SPEED (30 KM/H)

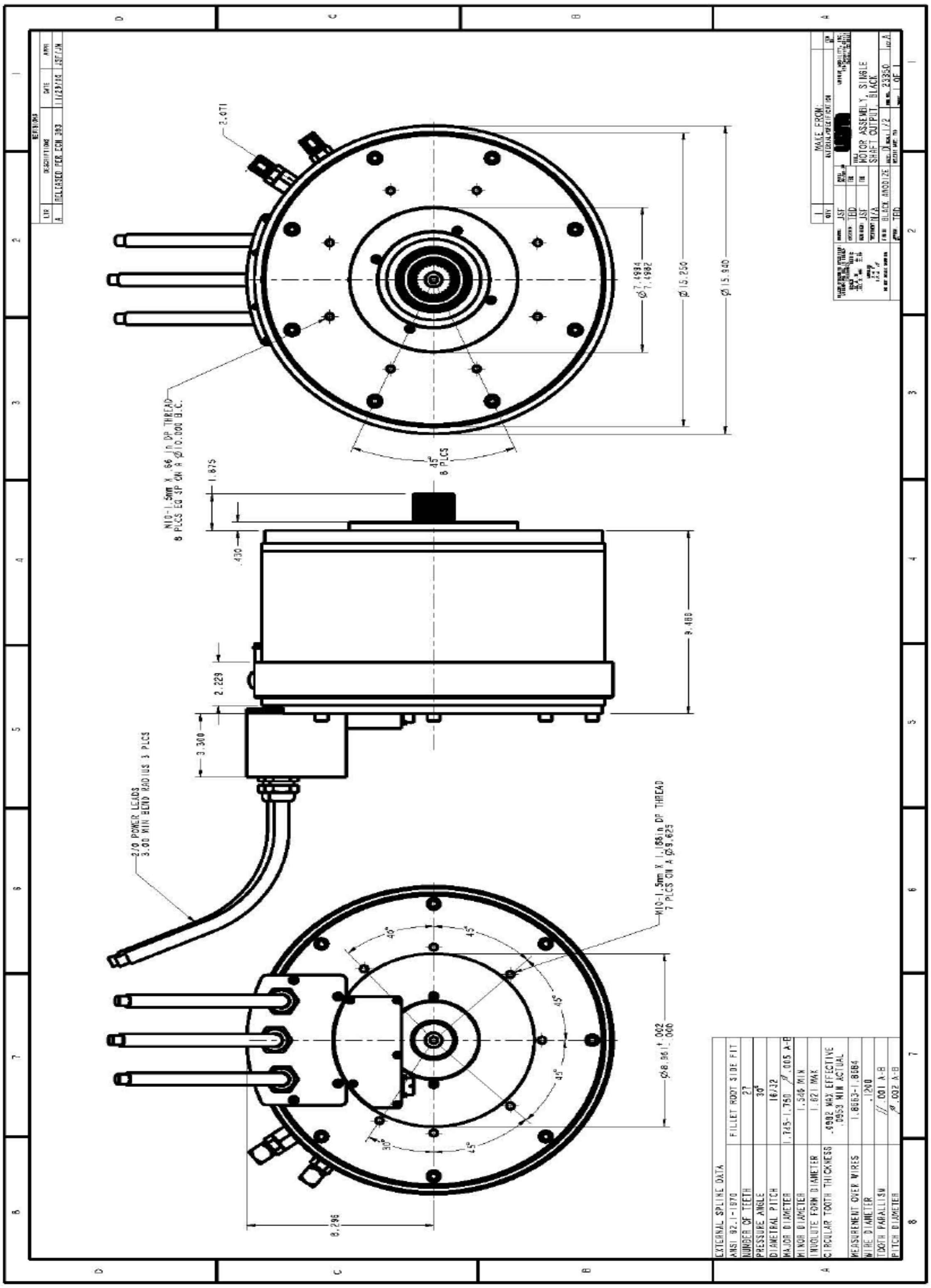
APPENDIX 8: MATLAB CODES OF BREAKING ENERGY@ CONDITIONS: CONSTANT ACCELERATION

APPENDIX 9: MATLAB CODES OF BREAKING DISTANCE

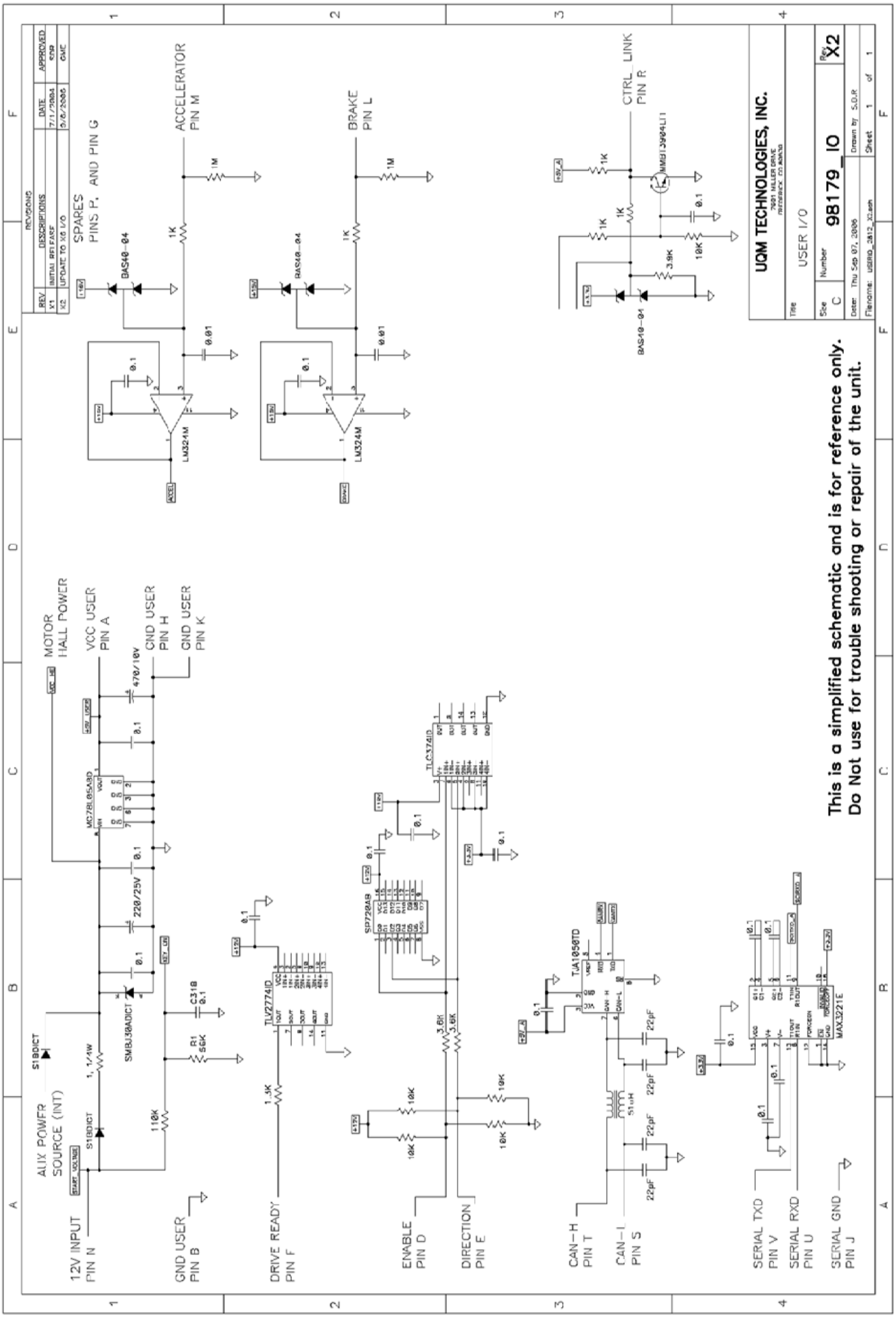
APPENDIX 1 : Electric Motor Hand Control Electric Interface



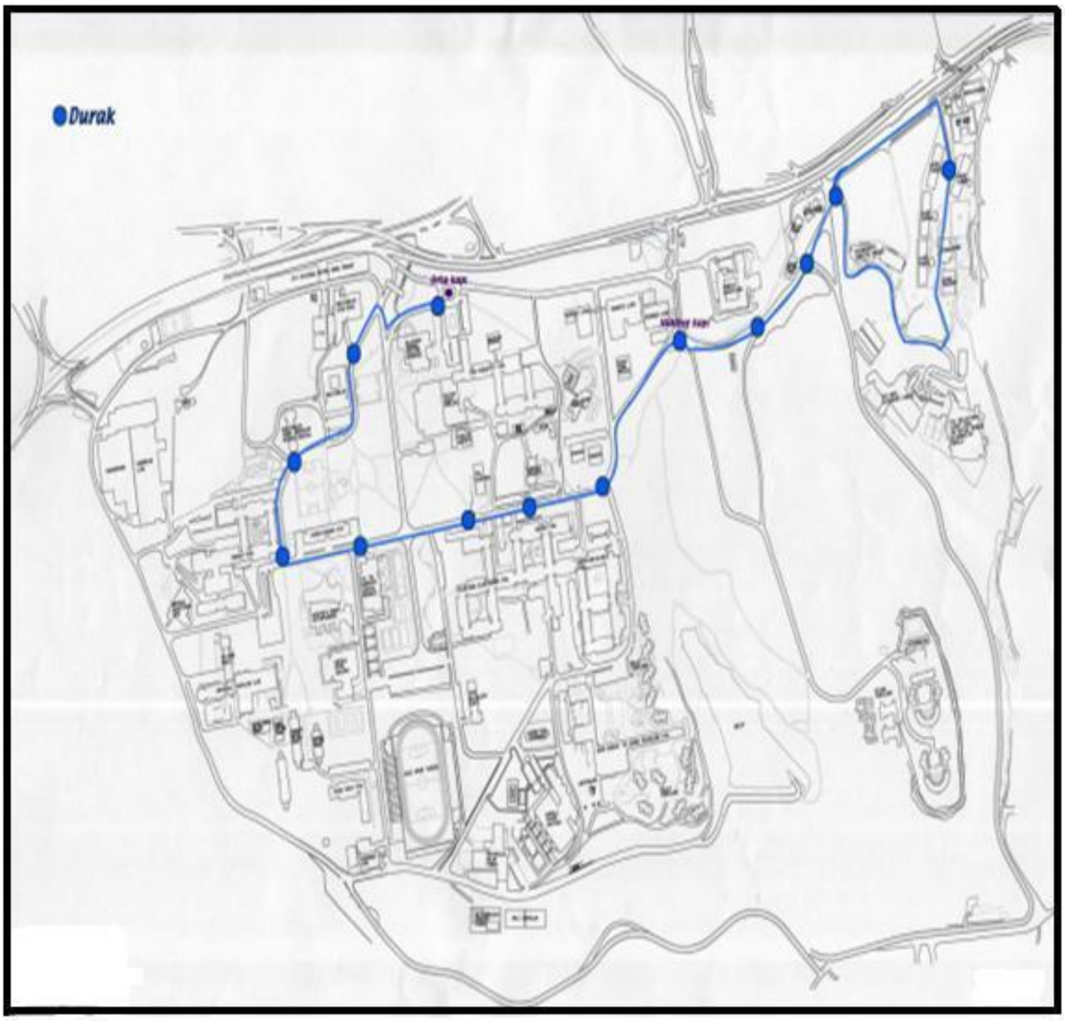
APPENDIX 2 : Inverter 2D Cad Data



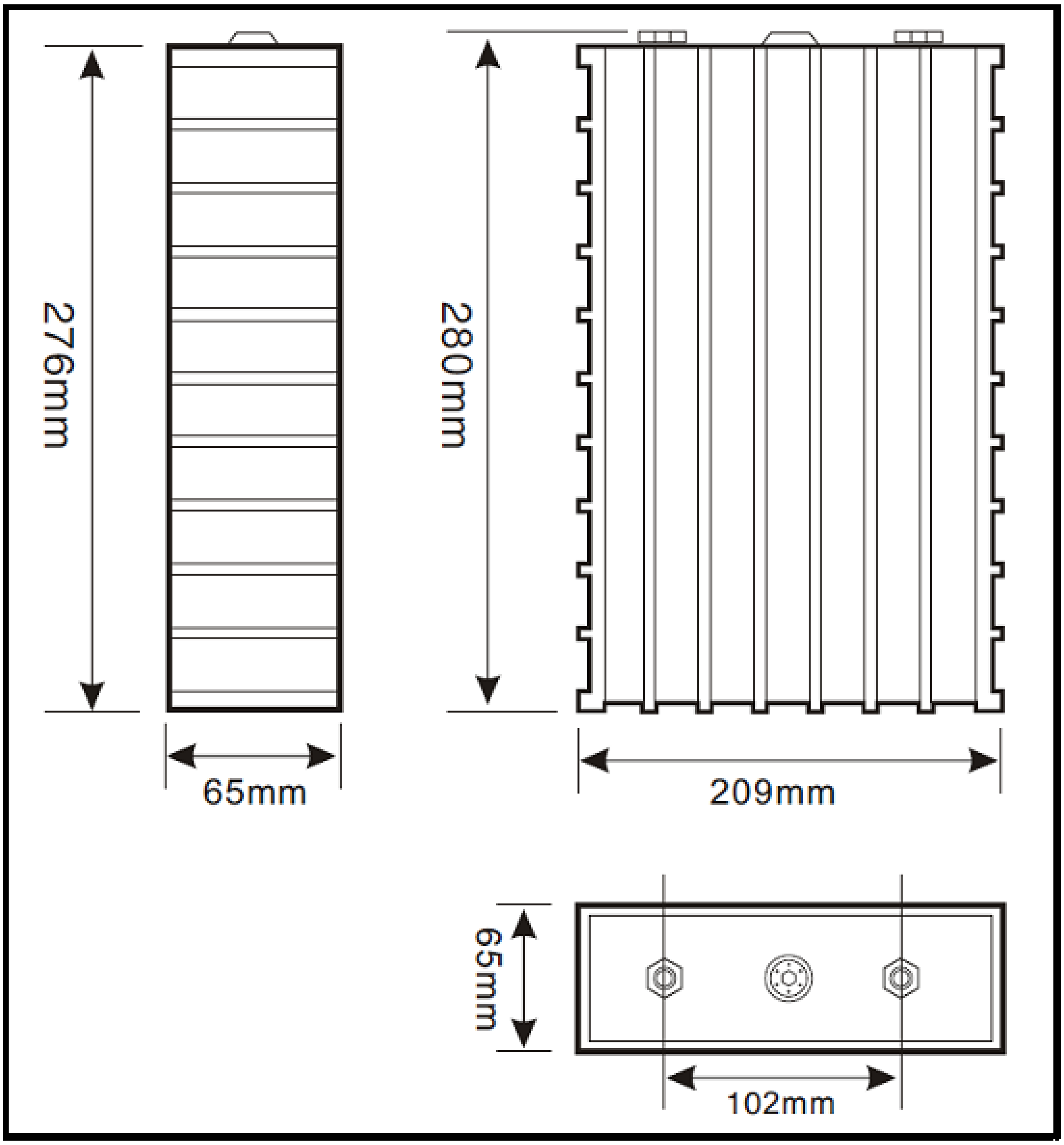
APPENDIX 3 : Electric Schematic of Electric Motor Control Circuit



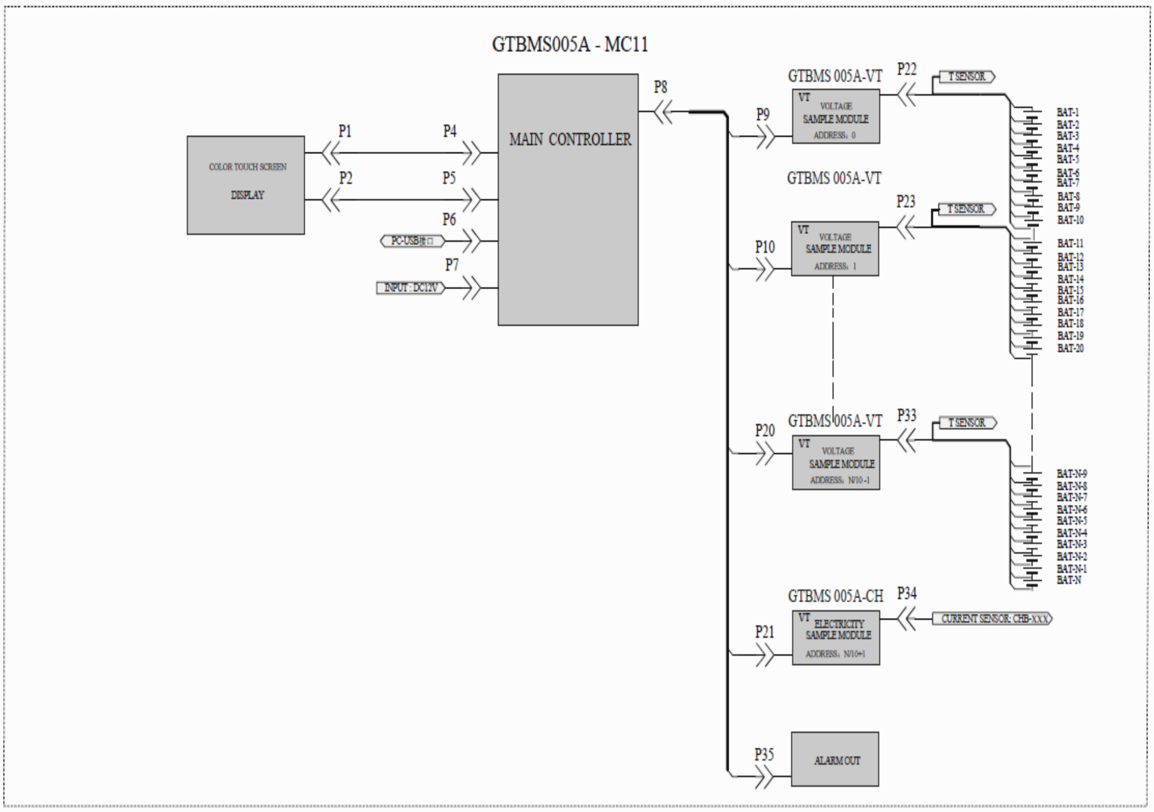
APPENDIX 4: ITU Maslak Campus Service Map



APPENDIX 5 : Battery 2D Cad Data



APPENDIX 6 : BMS System Principle



P1 : DB9 LINKER;(MALE)
P2 : 3P LINKER;
P4 : DB9 LINKER;(FEMALE)
P5 : 3P AVIATION LINKER;(MALE)
P6 : USB LINKER;
P7 : 2P AVIATION LINKER;(MALE)
P8 : DB25 LINKER;(MALE)
P9、P10、P20、P21 : 6P LINKER;(5557-6Y)
P22、P23、P33 : 14P LINKER;(5557-14Y)
P34 : 4P LINKER;(5557-4Y)
T SENSOR : DS18B20;
The direction of charge current should be according with the direction of current sensor arrowhead .

APPENDIX 7 : MATLAB CODES OF BREAKING ENERGY @ CONDITIONS: MAX. GRADIENT-FULL WEIGHT OF VEHICLE CONSTANT SPEED (30 KM/H)

```
fr=0.015                % CALCULATED FRICTION COEFFICIENT
y=1.14
ddx=9.8:-2:1.8;         % GRAVITATIONAL ACCELERATION CHANGE
z=ddx./9.81;            % FACTOR OF BREAKING RATIO
a_v=-9.81*z;            % ACCELERATION
g=9.81;                 % GRAVITY
M=4300*9.81;            % VEHICLE FULL LOAD WITH PASSANGERS
v=8.33;                 % VEHICLE SPEED-CONSTANT (m/s)
                        % P_fren=(fr+p+y.*a./g).*G.*v+Pl
q=1.266;                % AIR DENSITY @ 1 BAR 15 C DEGREE
cd=0.6;                 % AIR RESISTANCE FACTOR
A_f=1.9*2.4;            % FRONTAL AREA
Faero=0.5*q*cd*A_f*v^2; % AERODYNAMIC FORCE
P_fren=Faero*v;         % POWER

for i=1:length(ddx)
P(i)=(0.015-.12-ddx(i)/9.81*1.14)*M*v+P_fren ; % POWER DOT
t(i)=v/ddx(i);                                 % TIME DOT
end
subplot(2,1,1),plot(z,P,'--*'); grid;
title('% 12 GRADIENT ')
xlabel('BREAKING RATIO (z)');
ylabel('BREAKING POWER (watt)');
W=P.*t./2;
subplot(2,1,2),plot(z,W,'-*'); grid;
xlabel('BREAKING RATIO (z) ');
ylabel('BREAKING HEAT (joule)');
```

APPENDIX 8: MATLAB CODES OF BREAKING ENER @ CONDITIONS:

CONSTANT ACCELERATION

```
fr=0.0138                     % ROLLING RESISTANCE FACTOR_CALCULATED
y=1.14
a=-5;                         % ACCELERATION
g=9.81;                       % GRAVITY
M=4300*9.81;                  % WEIGHT
v=8.33;                       % VELOCITY
                              % P_fren=(fr+p+y.*a./g).*M.*v+Pl
                              % AIR RESISTANCE FORCE CALCULATION
q=1.266;                      % AIR DENSITY 1 Bar 15 C da
cd=0.6;                       % DRAG COEFFICIENT
A_f=1.9*2.4;                  % FRONTAL AREA
Faero=0.5*q*cd*A_f*v^2;         % AERODYNAMIC FORCE
P=Faero*v;                    % POWER
e=0.00:.01:.12;               % 5 m/s2 BREAKING ACCELERATION
for j=1:length(e)
118
P2(j)=(0.015-e(j)-5/9.81*1.14)*M*v+P ;
end
t2=v/5;
subplot(2,1,1),plot(e,P2,'-o'); grid;
title('5 m/s^2 BREAKING ACCELERATION ')
xlabel('GRADIENT');
ylabel('BREAKING POWER (watt)');
W2=P2.*t2./2;
subplot(2,1,2),plot(e,W2,'-o'); grid;
xlabel('GRADIENT');
ylabel('BREAKING HEAT (joule)');
```

APPENDIX 9 : MATLAB CODES OF BREAKING DISTANCE

```
% TIME FOR MAXIMUM BREAKING DISTANCE
tr=.4;
tb=.2;
ta=0.04;
ts=tb*1.1;
vo=5:2:11;
for i=1:length(vo)
St(i)=vo(i)*(tr+ta+ts/2)+vo(i)^2/2/9.81-9.81/24*ts^2
S1(i)=vo(i)*(tr+ta)
S2(i)=vo(i)*ts+(9.81/6)*ts^2
S3(i)=St(i)-S1(i)-S2(i)
end
subplot(2,1,1),plot(vo,St,'r--*'); grid;
xlabel('SPEED (m/s)');ylabel('STOPPING DISTANCE (m)')
% MAXIMUM BREAKING TIME;
for j=1:length(vo)
tt(j)=(tr+ta+ts/2)+vo(j)/9.81;
end
subplot(2,1,2), plot(vo,tt,'g-o');
grid;
xlabel('SPEED (m/s)');ylabel('STOPPING TIME (s)')
```

CURRICULUM VITAE

Candidate's full name : **Ahmet APAK**

Place and date of birth: **Aydın 10.10. 1985**

Permanent Address : Istanbul Technical University Maslak Campus Residences D2 Blok No:11 34469 Maslak –Sariyer – Istanbul ISTANBUL (AVR.) TURKEY

Universities and Colleges attended:

- **Undergraduate Izmir Institute of Technology** - (*Regular hours Education*) Engineering Faculty, Mechanical Engineering – *English* Izmir/TURKEY
- **Graduate M.Sc. (Continue)Istanbul Technical University** Institute of Pure and Applied Sciences, Mechatronic Engineering Istanbul/TURKEY

Publications:

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003794: Article Number in Conference 13&15 APRIL 2011
Corresponding Author Position on Article

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IEEE ICM (International Conference of Mechatronic) 2011
000256: Article Number in Conference 13&15 APRIL 2011
Member on Article