ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Fikri HANGÜL

STATIC ANALYSIS OF TWO SEATER EXTENDED RANGE ELECTRIC VEHICLE

DEPARTMENT OF AUTOMOTIVE ENGINEERING

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We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on

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ABSTRACT

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Electrical driven vehicles are becoming an attractive alternative to combustion engine cars. Electric vehicles will play quite an important role in reducing emissions in the future. One of the most effective ways for reducing fuel consumption and emissions can be achieved by reducing weight of the vehicle.

The vehicle chassis is one of the most important components of vehicle structure because of its versatile role on the dynamic behavior of the vehicle. There is a great potential for weight reduction of the chassis. This study presents the design and development of a two-seat prototype electric vehicle chassis. The main objectives are designing a battery module that can be easily attached and detached to the battery module compartment of the chassis, designing a new chassis model and ultimately evaluating the chassis for deformation based on static analysis of the entire structure. Vehicle designs and analyzes were done with Catia V5 R20 software. AL6061, ST-37 and carbon fiber materials are preferred for chassis.

Key Words: Lightweight Chassis and Body, Two-seated Electric Vehicle, Finite Element Method, Extended Range

ÖZ

YÜKSEK LİSANS TEZİ

MENZİLİ İYİLEŞTİRİLMİŞ İKİ KİŞİLİK ELEKTRİKLİ ARACIN STATİK ANALİZİ

Fikri HANGÜL

ÇUKUROVA ÜNİVERSİTESİ
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Elektrikli araçlar, son zamanlarda içten yanmalı motorlara cazip bir alternatif olarak görülmeye başlandı. Sera gazı emisyonlarının azaltımı noktasında elektrikli araçlar önemli rol oynayacaktır. Bununla beraber hem yakıt tüketiminin hem de emisyonların azaltılmasının en önemli aşaması daha hafif araçlar üretmektir.

Araç şasisi, taşıtın dinamik davranışı üzerindeki çok yönlü rolü nedeniyle, araç yapısının en önemli elemanlarından biridir.Özellikle şasinin ağırlık azaltımı konusunda ciddi potansiyeli mevcuttur. Bu çalışma, iki koltuklu prototip elektrikli araç şasisinin tasarımını ve geliştirilmesini sunmaktadır. Ana hedefler, ağırlığın azaltılması için uygun tasarımı kapsamında yeni bir şase tasarımı, doğru malzeme seçiminin yapılması, şasinin pil modülü bölmesine kolaylıkla takılıp çıkarılabilen bir akü modülünün tasarlanması ve nihayetinde tüm yapının statik analize dayanan şasi deformasyonunu değerlendirmektir. Araç ile ilgili tasarımlar ve analizler Catia V5 R20 yazılımı ile yapılmıştır. Şasi için AL6061, ST-37 ve karbon fiber malzemeleri tercih edilmiştir.

Anahtar Kelimeler: Hafifletilmiş Şasi ve Gövdesi, İki Kişilik Menzili İyileştirilmiş Elektrikli Araç, Sonlu Elemanlar Analizi

EXTENDED ABSTRACT

After the worldwide start of greenhouse gas and exhaust emissions as a serious problem, governments from the international arena, formed by the convergence of national states or states, have begun to take legislative measures to implement these measures in their countries by taking a series of measures to reduce greenhouse gas and exhaust emissions.

This, in particular, has put pressure on vehicle manufacturers to produce vehicles with lower emission values, which are less harmful to the environment. However, it can not be said that vehicle manufacturers have too many options to ensure that emission levels fall below a certain value. For this reason, vehicle manufacturers have been forced to produce lighter vehicles, aiming to reduce vehicle fuel consumption and reduce emissions to the vehicle per vehicle with reduced fuel consumption.

When the chassis and body of traditional vehicles are examined, it appears that they have a serious potential at the point of weight reduction. The fact that lighter and more robust materials can be produced with the development of technology has begun to present these materials as a serious alternative to heavy metals used in traditional vehicles. With the use of more lightweight and durable materials in the automotive sector, vehicle fuel consumption will decrease, which means that with the same amount of fuel consumption, the vehicle has extended range.

The change in the range of the vehicle as a result of the use of carbon-fiber composites and aluminum alloys, which are lighter materials instead of the heavy metals that make up the majority of the weight of the vehicle in our work and how to test these static materials with these materials and compare them to traditional metals, weight reduction is calculated. In order to make these comparisons, 4 different versions of the vehicle have been taken into account and the results of these versions are compared with each other. The total chassis weight of each

version was calculated, the vehicle was analyzed for static forces and the stresses and deformations that occurred in each version were calculated by using these materials. In version 0, the vehicle's upper chassis (monocoque chassis) is made of carbon fiber composite material, while the subframe (platform chassis) is made of aluminum alloys (AL6061). In the case of using these materials in the vehicle, the total weight of the vehicle's chassis, the voltage and deformation values of the vehicle chassis for the determination of the resistance of the vehicle to static forces, and finally, how long the vehicle will have to be used if these materials are used.

In version 1, the vehicle's upper chassis (monocoque chassis) is aluminum (AL6061), while the sub chassis (platform chassis) is designed using stainless steel (ST-37) materials. Version 2 is designed using the vehicle upper chassis (monocoque chassis) and lower chassis aluminum alloys (AL6061). Version 3 was designed using the vehicle upper chassis (monocoque chassis) and the lower chassis stainless steel (ST-37) material. The most extensively used version of stainless steel (ST-37), the most intensive of which is the result of calculations, has been the version with the most weight, the greatest stress and the smallest range. Similarly, the weight of version 1 used in ST-37 and AL6061 as chassis material was the second with the least range, the least. Version 1 was followed by version 2 in terms of weight and range, with version 3 and version 1 being the third version with maximum weight and minimum range. The version 0, which uses carbon fiber materials known for its low density and strength, is the version with the lightest chassis weight, minimal deformation and the longest range.

As can be understood from the analysis and calculations made, the use of alumium alloys and, more importantly, carbon fiber composites with a high strength property and a low material density, and the reduction of the weight of the vehicle and consequently the reduction of fuel consumption, the longer the vehicle has the longer range and the better the static forces of the chassis the advantages of having performance.

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Last but not least, I would like to thank my wife and parents.

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ABBREVIATIONS

EV	:Electric Vehicle
US	:United States
AIV	:Densified aluminum vehicles
PEG	:Porsche Engineering Group
ULSAB	:Ultra-light steel auto body
BIW	:Body in White
FOS	:factor of safety
EU	:Europan Union
mAh	:Miliamper
V	:Volt
Ah	:Amperhour
AC	:Alternative Current
DC	:Direct Current
BLDC	:Brushless DC
UM	:Universal Motor
PMDC	:Permanent Magnet DC
FEM	:Finite Element Method
CAD	:Computer Aided Design
CAM	:Computer Aided Manufacture
3D	:3 Dimensions
MPa	:Mega Pascal
eta	:Efficiency
rw	:Tire radius, m
itran	:Transmission gear ratio
mv	:Vehicle mass, kg
Af	:Frontal Area m^2
Cd	:Drag Coefficient

T	:Motor output tork
vo	:Wind speed
rho	:Density of air
g	:Gravitational acceleration
alpha	:Slope angle
Fa	:Aerodynamic Loss
Fr	:Rolling resistance
Fg	:Gravitational Forces
ICE	:Internal Combustion Engine

1. INTRODUCTION

1.1. Electric Vehicles' History

1.1.1. Between 1830 and 1890s

The first attempts in the development of electric cars was towards the end of 18th century. In the 1830's, engineers and scientists made a number of different breakthroughs for the development of electrically powered vehicle technology. In this period, countries such as the United States, Hungary and the Netherlands, which created the first small-scale electric vehicle models, made some significant innovations. The first electric wheel drive vehicle was developed by Robert Anderson in 1832 (Matulka, 2014). However, this car was quite far from being practic vehicle. United States' first electric car was produced by the inventor William Morrison in Iowa in the 19th century, and the interest for this car was very considerable. The beginning of the next century, horses continued to be used as the main means for transportation. However, for personal use, three different drive technologies have emerged: gasoline, electricity and steam. The steam engine is not particularly suitable for personal use due to its long start-up times, generally during cold winter months. The engine took about 45 minutes to warm up and the another limiting factor was water tank.The gasoline internal combustion engine managed the range factor. However, the driver already had to shift gears to drive the car, which made the car difficult to control and the engine od vehicle had to be operated by a hand crank.

1.1.2. Between 1890s and 1935

On the other hand, the electrically motor did not encounter none of the above-mentioned challenges. Electrically-powered automobiles were gaining popularity among women in the 20th century and with the addition of other factors. When compared to a petrol engine, the former profit was a non-emission engine and was great for short-range traffic. These realities have had an impact on the

market and electric vehicles have introduced the new century with 28% market in the United States (Curtis D. Anderson, 2010). The creaters of this period had certainly noticed this and in 1891 Ferdinand Porsche introduced the P1 model. P1 model was first car of campany and it was powered by electricity. In 1914, Thomas Edison and Henry Ford met in order to develop economical electric cars for large masses (Strohl, 2010). The first series-built vehicles which have an internal combustion engine (ICE), Model-T of Ford company, came on an electric vehicle in 1908. A very inexpensive car for large mass was represented by a $ 650 price tag, while electric roadsters had an almost triple price tag of $ 1,750. Furthermore, in 1912, an electrically starter was produced, which lifted a major loss of the hand crank and increased the sales of ICE cars. The major improvements in the market, especially in the US, were the gas and petrol stations of the 1920s. On the other hand, electricity was still not reachable in rural regions at that time, and eventually about 1935, electric vehicles were defeated by ICE vehicles and dissolved from the market for ages (Matulka, 2014).

1.1.3. 1935 – 1990

Over the next 40 years, the dominance of the ICE vehicles has led not to the development of electric motor technology and its target on burning in general. Petrol's cheap prices and constant focus on improving combustion efficiency left electric cars in the dark. The Clean Air Act was organized in 1970, which is responsible for fulfilling certain air quality objectives of any American state. In the late 1970s, oil prices in the world began to rise and oil supplies finally began to be seen as restricted. In 1973 with the Arab oil embargo, oil prices peaked in the United States and this situation was lead to less dependence on foreign oil resources and exploring home-built oil resources. Only three years later, the government intended to investigate alternative fuel possibilities for the 1976 Electric and Hybrid Vehicle Research, Development and Demonstration Act (Matulka, 2014). France organized the "PREDIT" program in 1976 after similar

oil price problems to strengthen the electric car RD & D (Curtis D. Anderson, 2010). During this period, the two companies were really small but dominated the current electric car market. The first and more successful was the Florida-based manufacturer Sebring-Vanguard, which produced more than 2000 "CityCars" in the 1970s. Second, it was developed by Alcar Corporation and has become less popular. CityCar stay the top-selling electric vehicle in the US till the Tesla model Roadster emerged in 2006. The German car maker BMW, they introduced the 1602 E model. This car worked on a 42-horsepower (hp) 37-mile, single-charge, all-electric motor. However, in addition to its use in the Olympic Games, the electric motor vehicle never reached serial production (Thompson, 2015). There was little eagerness for electric vehicles until the early 1990s.

1.1.4. 1990s – Today

In addition to the Energy Policy Actand Clean Air Act Amendment, transportation emissions regulations in California have rised attraction to electric cars in the United States. In California, the Air Resources Board was stipulating that automakers had to buy and sell a none emissions car to insert them on the government's strategy (Curtis D. Anderson, 2010). In the meantime, General Motors(GM) introduced the EV1, the company's first example. It was great sell number for electric cars on the American market. The most important contribution for electric vehicles is that it is the excitement and enthusiasm of the public for the first time in electric vehicles. It has become a leader car in its segment, and it already sold 1117 units during the first year of production in 1996. But General Motors could not make the electric car profitable for the company and removed from the market during 2001 (Brown, 2016). Another important case was Toyota developed its Prius and introduced to the market in 1997. It was hybrid electric vehicle. It was the best-selling hybrid car of the first decade of the 21st century. In 2006 in the Silicon Valley, a new company is emerged. Tesla Motors as a full electric model with their first car Tesla Roadster. The company's energy situation

has changed significantly. The US Department of Energy has given Tesla Motors a $ 465 million loan, and the company was able to pay back totally in 2013. The money was spent to the developing of the giga factory, which made Tesla the largest vehicle maker in California (Matulka, 2014). Because of Tesla's fantastic achievement, electric cars encourage other big car makers, so between 2010 and 2013 Nissan produced its electric car and Chevrolet produced its hybrid model Volt. In 2013, BMW produced the hybrid i8 and all-electric i3 and. The main trend of EVs in recent years is to have hybrid technology installed in the model of every big car manufacturer.

1.2. Advantages and Challenges for Electric Automobiles

1.2.1. Advantages of EV over Combustion Engine Vehicles

The most important benefit of an electric vehicle over ICE car is its zero exhaust emissions, which is an indisputable fact. Nevertheless, the electric source for the driving the motor still required to be obtain somewhere to supply its usage. For this reason, EVs shift air pollution only to the production of electric power plants used for fossil fuels for production (Adolfo Perujo, 2011). It is easier to manage the emissions produced by power plants in a unified manner in the plants, with much higher carbon dioxide yields than if the daily traffic had to be a single car in very large quantities. Another criteria is the elimination of noise causes from traffic, because the operation of the EV's engine is considerably quieter (Adolfo Perujo, 2011).

Another important benefit of any electric vehicle is its lower cost of consumption. In addition, consumption of EVs' kWhs represents a important difference in the consume of any petrol or diesel car. On the move, the electric motor completely bypasses the gearbox with the clutch and compose of only a few rotary particles, unlike the ICE. For this reason, the motor does not need to make any changes in oil, coolant water or sparks of any kind. This situation is a consumer-oriented feature of motor components that will be kept at lower

maintenance costs (Jha, 2013). Electric vehicles are usually powered by the regenerative engine braking system when the foot pedal is lifted. This step finally extends the life of the brake pads and at the same time charges the batteries when braking. The normal efficiency of today's ICE's is between 25% and 35% of how they work with fuels. On the other hand, the efficiency of electric motors is more than three quarts, minimum 90% (Boxwell, 2014). The other positive effect of the eliminating transmission and the general structure of the electrical unit is a momentary torque, which provides high power from the stall, while a ICE can only do so at high speed (Boxwell, 2014). Power distribution is performed in a very smooth and accessible manner on any drive in the drive, allowing a fast response time. Finally, more seriously, the purchase of a new electric car, in many countries promoted by the government, raises the public's interest in buying EVs on traditional cars to decrease the country's dependence on external oil. This is generally true for electric BEVs, but the subsidy of hybrid cars can be considered in many destinations.

1.2.2. Challenges and Barriers for EVs

1.2.2.1. Batteries and Range

The biggest obstacle to purchasing any EV is a single charge of the vehicle, much lower than for a fully loaded traditional car. Today, the big part of the electric vehicle market can only drive between 80 and 160 km with one charging (up to 500 km, but so expensive with Tesla) (Boxwell, 2014). This can be regarded enough for daily distance for community, but is still not comparable to the range of any ICE motor vehicle. They generally reach 500km distance with just one single tank. For regularly traveling long range drivers, the limited distance can be an issue. If we continue talking in the range of vehicle traffic, it is significantly reduced when operating on the highway at a speed greater than 130km / h, which requires more power in the car. But EVs running at speeds of up to 110 km / h are often well managed without significant falls in range (Boxwell, 2014).

1.2.2.2. Charging

While someone has an electric vehicle, the essetial requirement is to be able to charge it appropriately to calm the anxieties. In the case of limited distances around the city, the normal car interval is sufficient for one day when traveling to workplaces, grocery stores or schools. In case of not using the car, the big part of the EV owners (95%) generally charge their cars' batteries at the night (Boxwell, 2014). Most of people put their cars on the street and must be fortunate to have any public charging points around community (Erjavec, 2012). The other problem emerges for journeys longer than the charging distance of the car. In this situation, consumers are compelled to trust the network of charging stations. Charging time is the other poblem that can be done aim of fast chargers and adds the range of the car in less than an hour. However, the place where they come to today is quite rare (Erjavec, 2012).

1.2.2.3. Purchase Price

Eventually, the question about the cost of purchasing any electric vehicle is usually over than the classical and quality segments of other traditional market products. The main reason why electric cars are so expensive is that they are the main reason for the price of batteries, which today is facing the price of 350 USD at 1 kWh (Wesoff, 2016). Let's observe a fully battery-powered electric Chevrolet Boltas an example, capacity of battery is 60 kWh and the sell price is around US $ 37,495. Considering the above 1 kWh price, we are facing the price of battery 21.000 USD which is bigger than half of the last sale price (Edelstein, 2017). This is the reason why electric cars are more expensive than competitive rivals, while trying to offer affordable cars while making it difficult for automakers to satisfy the profit margins.

1.3. Exhaust Emissions and Heavy Vehicles

The technical improvements of vehicle design plays a very important role in reducing of exhaust emissions. Especially, increasing environmental concerns about global warming puts extra pressure on development of environmentally friendly transportation systems. This is one of the reasons why Electric Vehicles (EV) are becoming an attractive alternative to combustion engine cars due to environmental concerns.

One of the main reasons is the exhaust emissions and its contribution to greenhouse gases and global warming. The exhaust emissions are type of gases that have the ability to retain heat in the atmosphere. This is the main reason for categorization as greenhouse gases. The main effect of increasing greenhouse gas emissions is that they lead to global warming. Fluorinated gases, carbon dioxide, nitrous oxide and methane all contribute to trapping the heat in the Earth's atmosphere as a part of their greenhouse effect. The largest share of greenhouse gas emissions are generated by transportation sector. In 2016, transport-related greenhouse gas emissions accounted for about 28.5 percent of total US greenhouse gas emissions (US Environmental Protection Agency, 2017). The CO2 emissions from cargo transport are 23% of the whole world and 30% of the OECD (International Transport Forum, 2010). The energy consumption is another important effect of road transport along with greenhouse gas emissions. The International Energy Forecast report predicts that world energy consumption will increase by 48% between 2012 and 2040. The global road energy demand for road transport is projected to be increased by 30% between 2014 and 2040 (The International Energy Forecast, 2016).

Today, automotive industry faces some of the most important technical problems of its history. Regulations and legislation are being implemented in many regions of the world to perform higher fuel economy and lower exhaust emissions. In any case, the trend is up and some regions, the implementing regulations put much more emphasis on improving the fuel economy.

US Ministry of Energy says reducing the car's weight by only 10 percent can increase fuel economy by 6 to 8 percent (Motavalli, 2012). The leading companies in the automotive industry have begun to use alternative materials to lighten their vehicles. Ford has used carbon fiber in certain niche applications such as an internal engine cover lid for the Ford GT super car and a title for the Shelby GT500KR (Motavalli, 2012). Earlier this year, the company announced it was collaborating with Dow Automotive Systems to develop low cost carbon fiber composites for mass production. It was estimated thet it would be possible to reduce the weight by 750 pounds (Motavalli, 2012).

Ronald P. Krupitzer, vice president of automotive applications at division of the American Iron and Steel Institute, said that "about 60 percent of automobile weight is steel or its derivatives." Since 2000, the industry has doubled existing steel qualities and increased the strength levels by 50 to 100 percent. He also mentioned that "The steel available for car companies now is up to five times stronger than the steel used 10 years ago". It was reported by Motavalli that "A part that weighed 100 pounds is being replaced by one that's 75 pounds, with no price increase" (Motavalli, 2012).

The BMW i3, a battery- powered electric car designed for urban use, has a carbon fiber reinforced plastic upper body structure that sits on aluminum chassis as shown Figure 1.1.

Figure 1.1. BMW composite body (Anonymous, 2018a)

According to a recent study, every 100 kg weight reduction, results with 0.3 L/100 km for cars and 0.4 L/100 km for light trucks. In other words, every 10% weight reduction in the vehicle's body reduces the vehicle's fuel consumption by %6 to %7 (Cheah, 2010).

The following tablature weights (MIT, 2008) have been given to fuel savings in response to the weight loss of cars and commercial vehicles ranging from 1000 to 3800 kg.

Table 1.1.Estimated fuel economy based on the drop in vehicle weight

Reduction Amount	Estimated fuel savings for cars over 200,000 km	Estimated fuel savings over 200,000 km for commercial vehicles
10 kg	$65	$87
25 kg	$164	$218
50 kg	$327	$436
100 kg	$654	$872
200 kg	$1,308	$1,744
400 kg	$2,616	$3,488
1,000 kg	$6,540	$8,720

1.4. Aim of Study

Weight reduction is now one of the main problems in the automotive industry as the weight of the vehicle increases, the fuel consumption also increases. At the same time, the weight of the vehicle increases the cost which becomes a major issue when purchasing a new automobile.

When the traditional chassis is examined, it is understood that they are usually made of steel and steel alloys, aluminum and aluminum alloys, magnesium and magnesium alloys. As well as the disadvantages of using these metallic materials in chassis, they have many advantages that can not be overlooked. Because these materials increase vehicle chassis weights. Namely, they often increase the fuel consumption and emissions and while affecting the vehicle performance negatively. Table 1.2 (Savage, 2010) shows comparison of mechanical properties metallic materials and composite materials.

Table 1.2. Mechanic properties of composite and metallic materials(Savage, 2010)

Material	Specific Strength (σ/ρ)	Tensile Strength, σ (MPa)	Elasticity Module, E (GPa)	Specific tensile modulus (E/ρ)	Density (g/cm3)
Steel	167	1300	200	26	7,8
Aluminum	124	350	73	26	2,81
Magnesium	150	270	45	25	1,8
Aramid	1060	1400	45	57	1,32
IM Carbon	1656	2500	151	100	1,51
HM Carbon	1006	1550	212	138	1,54
Titanium	204	900	108	25	4
E Glass	524	1100	75	21,5	2,1

The composite materials are of interest because they are lightweight, high specific coefficients (E / ρ), high specific strength (σ / ρ), and higher abrasion resistance compared to most metallic materials.

The composite materials are widely used in aircraft industry, space and rocket industry, marine industry and automotive industry due to their lightweight structure and superior properties due to their advantages compared to metallic materials listed below.

- High corrosion resistance
- High heat resistance
- Easy to repair
- High damping feature
- Lightweight structure
- Long service life.

Today, composite materials are being used in various fields of the automotive industry. In the production of chassis, body and some mechanical parts of vehicles, composite materials are the being used already.

The BMW brand produced the cockpit zone from the carbon fiber composite in the model I8. Carbon fiber is 30% lighter than 50% aluminum, while the durability and collision safety properties of the material remain the same.

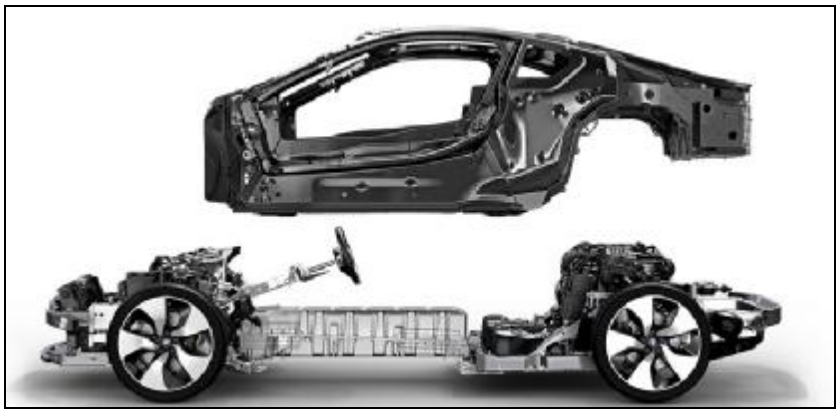

Figure 1.2. BMW I8 composite body (Anonymous 2018b)

Given that a significant portion of the vehicle weight constitutes chassis weight, the use of lightweight composite material in chassis production can significantly reduce the overall vehicle weight. It is important that material stability and collision safety must not be overlooked, while reducing the weight of the chassis.

Electric motor vehicles have a range problem as compared to internal combustion engines. In recent years, significant increaments have been observed in the work done to solve this problem. Electric vehicles differ from internal combustion engine vehicles due to the components they contain An electrical powered vehicle typically includes an electric motor and drive train supported on a frame and enclosed in a body. A battery or bank of batteries are supported on the frame and connect to the electric motor to supply power for the electric motor as well as the rest of electronic system on board. The battery or battery bank significantly increases the vehicle weight, so it must be designed according to certain parameters. Therefore, battery packs should be lighter and accessible to be removed easily.

The main objective of this study is to increase the range of the EV. In order to enhance the range of vehicle, two different methods are considered. Firstly, the weight of the vehicle body is lightened by using lightweight materials. Secondly, the problem about battery pack replacement is addressed by designing the system to allow rapidly removable battery packs on chassis. In order to achieve all these in one chassis, a new concept chassis is designed and analyzed to serve as a two seater electric drive vehicle. The presented design study provides details on the design process as well as the analysis tasks performed on the system.

2. PRELIMINARY WORK

2.1. Vehicle Weight Reduction Literature Review

There are several studies reported in literature that present a light weight vehicle design by using aluminum alloys instead of steel. In 1995, Stodolsky et al. realized a study which predicts total life-cycle energy savings over time as densified aluminum vehicles (AIVs). Their study shows that cars and light trucks have a potential for 19-31% lightening with the intensive use of aluminum. This seems to increase the fuel economy by 12.5-20% for AIVs over conventional steel vehicles. They defined three ways to reduce weight of a vehicle in their study. They reduce the vehicles' size, optimize its design to minimize weight, and replace the materials used in its construction with lighter mass equivalents. According to the Stodolsky et al. the third option is to use lightweight materials that could make bigger gains (Stodolsky et al., 1995).

One of the aluminum intensive vehicles in the automotive industry is manufactured by Ford Company. In 1994, Ford produced a small show fleet Mercury Sables with an aluminum body. Gaines and Cuenca researched with Mercury Sables with aluminum bodies and the primary purpose of their search was to observe the wear characteristics of the body under working conditions. Even though measurement of fuel economy was not considered in the scope of their study, their experience during six years of operation demonstrated that the AIV was a very practical car with perfect performance and a fuel economy compared to an equivalent steel-body car (Gaines and Cuenca, 2002).

In addition, there are a lot of studies which get lightweight body by using high strength steel. One of these studies is carried out by Porsche Engineering Group Porsche Engineering Group (PEG) signed an agreement with world's sheet steel producers to design the ultra-light steel auto body (ULSAB). The purpose of the ULSAB program was to build a light-weight body structure design that is primarily steel. The purpose of their study was obtaining a considerable mass

reduction based on a future reference vehicle, corresponding functional and structural performance targets, supplying concepts that will be practicable for new version of car programs. In 1998, the consortium presented to the world automotive industry, a complete ULSAB body-in-white, which dramatically confirms the design criteria and concepts. The benchmark design used by PEG for comparison had a BIW mass of 271 kg. In 1998, the resulting body design, which made extensive use of high strength steels, weighed 203 kg, a reduction of 25% (Porsche Engineering Services, 1998).

In the next period, the optimal lightweight design studies carried out by using multi- material structures. William J. Joost who determined the relationship between U.S. transportation energy and vehicle weight and checked the most promising lightweight materials, indicated that the optimal lightweight designs typically involve the use of multi-material structures in his study (Joost, 2012).

In 2015, Wagner et al. represented the potential of multi-material lightweight vehicle (MMLV) design for reducing weight of a five-passenger car meanwhile maintaining crucial safety metrics and vehicle performance. In their design work, aluminum, steel and lightweight materials were combined. They obtained a 364 kg (23.4%) weight reduction comparing with 2013 Fusion baseline. In turn, that weight reducing enables use of a 1.0-liter three-cylinder engine, remarkably increasing fuel economy and reduces CO_2 emissions. They stated that the automotive industry proceeds to search innovative ways to include lightweight materials which are both affordable and cost effective (Wagner et. al., 2015).

Patel et al. (2013) designed the model of the chassis in solidworks and analyzed the chassis frame on static loads. The reported analysis was performed using finite element method software ansys to achieve optimal chassis design with factor of safety (FOS) 3 (Patel et al., 2013).

Vaidya et al. (2004) designed and manufactured glass/PP composite panel for the floor area of a mass production type of transit bus. This composite floor

panel was 40% lighter than the conventional metal/plywood design (Vaidya et al.,2004).

2.2. Removable Battery Pack Literature Review

Several studies were carried out in literature to design removable battery packs in order to extend vehicle range. The EU-funded Optimized storage integration for the electric car (OSTLER) project sets off to develop new approach for battery integration in cars (Electric Vehicles Research, 2015). The aim was to search the feasibility of an interchangeable, portable battery concept that accord with all relevant automotive regulations. The OSTLER team constructed smart concepts to insulate battery packs in EVs. To do so, they explored the influences of large battery packs on vehicle crashworthiness to indicate the most defenseless type of battery cell. A prototype battery pack was designed for this function and active and passive solutions were developed to guard it in case of crash. Physical tests and dynamic simulations defined the performance of both systems. Especially, the effective solution composing of an distensible light textile construction demonstrated satisfying performance and low weight (Electric Vehicles Research, 2015).

In US8146694B2 patent, Hamidi designed an arrangement for removable battery pack for EV. Each battery unit included a battery compartment housing, a battery compartment shelf that could slide into the battery compartment housing. The battery carrier bracket also contained a majority of modular battery packs positioned in the loading boxes. In order to exchange regulated battery packs, the slideable battery carrier shelf was going out from one side (Hamidi, 2009).

Sujie Shao et al. (2017)presented a novel approachment to provide a mobile battery removable service for EVs. That battery swapping van could carry many fully charged batteries and drive up to an EV to swap a battery with in a few minutes (Shao et al., 2017).

Tesla Inc. filed a patent (US20150307068A1) about a method of exchanging an electrical energy storage system in an EV. Tesla battery-swapping system that can lift up a vehicle and change out its battery packs for just a few minutes (Gaffoglio et al.,2014).

3. MATERIAL

3.1. Lightweight Materials

Lightweight materials are aluminum, magnesium, titanium, advanced high-strength steels, as well as polymer-matrix composites strengthened with carbon fibers and glass. A list of the lightweight materials and their potential for weight reduction are shown in Table 3.1 (U.S. Department of Energy, 2010).

Table 3.1. Potential vehicle materials substitution

Lightweight Material	Material Replaced	Mass Reduction	Relative Cost
High Strength Steel	Mild Steel	10	1
Magnesium	Steel or Cast Iron	60-75	1.5- 2.5
Magnesium	Aluminum	25-35	1-1.5
Glass Fiber	Steel	25-35	1-1.5
Aluminum Metal	Steel or Cast Iron	50-65	1.5-3+
Stainless Steel	Carbon Steel	20-45	1.2-1.7
Aluminum	Steel, Cast Iron	40-60	1.3-2
Graphite FRP Composites	Steel	50-60	2-10+
Titanium	Alloy Steel	40-55	1.5-10+

In automotive industry, many materials are used to reduce weight such as magnesium alloy, aluminum alloys, high strength steel and composites. In addition, these materials should compensate performance requirements (sufficiently well-characterized, strong, easily formed and joined into assemblies and components, durable) for vehicle design. Table 3.2 shows comparison of the materials properties (Cheah, 2010).

Table 3.2. Relevant properties of automotive materials (Cheah, 2010)

Material	Density g/cm3	Stiffness Thickness ratio	Elastic Modulus GPa	Yield Strength MPa	Strength Thickness ratio	Tensile Strength MPa
Mild Steel	7.86	1.00	200	200	1.00	300
High Strength Steel	7.87	0.99	205	345	0.64	483
Iron	7.10	-	166	276	-	414
Aluminum	2.71	1.42	70	275	0.85	295
Magnesium	1.77	1.64	45	124	1.27	228
Composites -Carbon Fiber -Glass Fiber	1.57	1.01	190	200	-	810

3.2. Composite Materials

A composite material is described as a material composed of two or more materials combined on a macroscopic scale by mechanical and chemical bonds (Rajagopal et al. 2014) .Unique feature of many fiber strengthened composites is their advanced internal absorbing capacity. This lead to improve vibration energy damping within the material and result in reduced noise transmission to circumjacent structures. Many composite materials purpose a combination of endurance and modulus that are either comparable with or better than any conventional metallic metals (Callister, 2007).

Due to their low specific gravities, the modulus to weight-ratios and strength to weight-ratio of these composite materials are considerably superior to

those of metallic materials. Both weight ratios and fatigue strength and fatigue damage toleration of many composite laminates are almost wonderful. Therefore, fiber composites have revealed as a major class of constructional material and are either used or being considered as placement for metals in many weight-critical components in automotive, aerospace and many other industries. Advanced absorbing capacity of these materials can be utilized in many applications in which vibration, noise and hardness are very critical issues for passenger comfort in automotive industry.

3.3. Materials of Study

3.3.1. Battery

A battery is an electromechanical appliance that converts chemical energy to electrical energy, using the galvanic cell. The galvanic cell is a device composing of an electrolyte solution and two electrodes (an anode and a cathode) (European Commission DG Environment, 2008).

The difference between a battery and a cell is that a battery is a collection of cells while a cell is a single unit that converts chemical energy into electrical energy. There are three types of battery cells used by automotive producers: prismatic, cylindrical and pouch cells. A symbolic prismatic cell is preserved by made of metal or hard plastic. Cylindrical cell cases frequently consist of aluminum and pouch cells use lightweight cases made of a layered foil consisting of sheets of polymer and aluminum welded together around the edges of the flat cell.

Due to its low price and light weight, prismatic –cells are one of the most widespread cell design high battery capacity. The prismatic cell satisfies the demand for lower manufacturing costs and thinner sizes. Prismatic cells are encountering into larger forms. Packed in welded aluminum housings, the ordinary cells deliver capacities of 20 to 40 Ah or even more power and are firstly used for

electric power trains in electric and hybrid vehicles. Figure 3.1 shows the cross section of a prismatic cell.

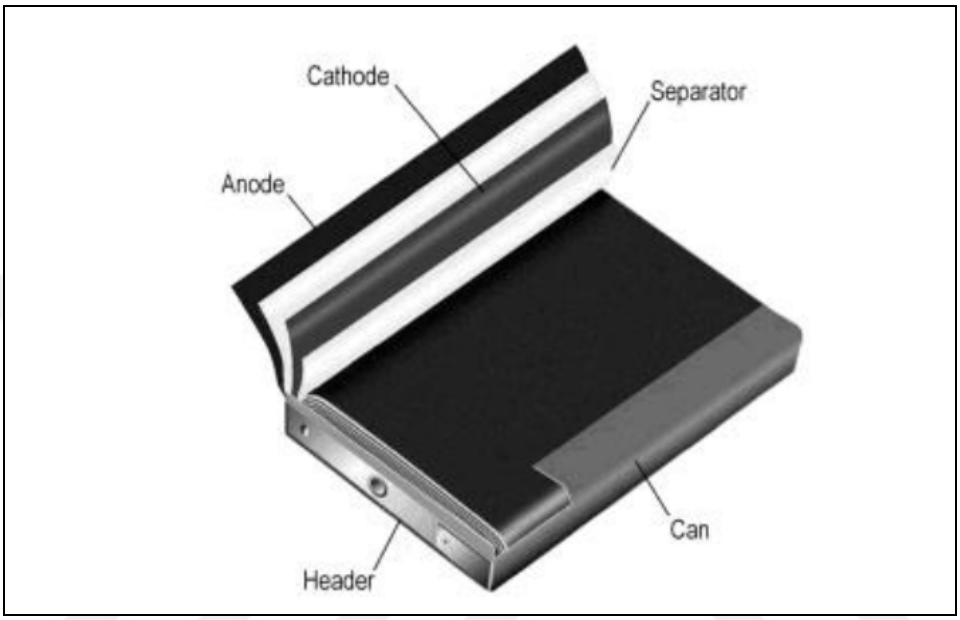

Figure 3.1. Representative sample of a prismatic cell (Anonymous, 2018c)

3.3.1.1. Voltage

Nominal voltage of the LiPo cell is 3.7V. In order to get 7.4V battery, two cells must be connected in series which means the voltage gets added together.

3.3.1.2. Capacity

Battery capacity is basically measuring of how much power battery can hold. Milliamp hours (mAh) is the measure unit. This means how much drain can be turn on the battery to release it in one hour.

Battery capacity is like a fuel tank - it means that the capacity determines how long it can run before being charged. The higher capacity, the longer running time. However, the bigger the capacity, the bigger the physical size and so bigger weight of the battery.

3.3.1.3. Series

Cells are connected in series in order to rise the voltage during battery terminals. Series means loading the cells end-to-end, joining the anode of one to the cathode of the next.

By joining batteries in series, sum of the voltage is increased. Operating voltage is determined by adding the voltage of all the cells. The capacity does not change. Figure 3.2 shows connection of four 1.5 V cells in series. The total voltage of loads is 6 V while batteries have a 2000 mAh capacity totally.

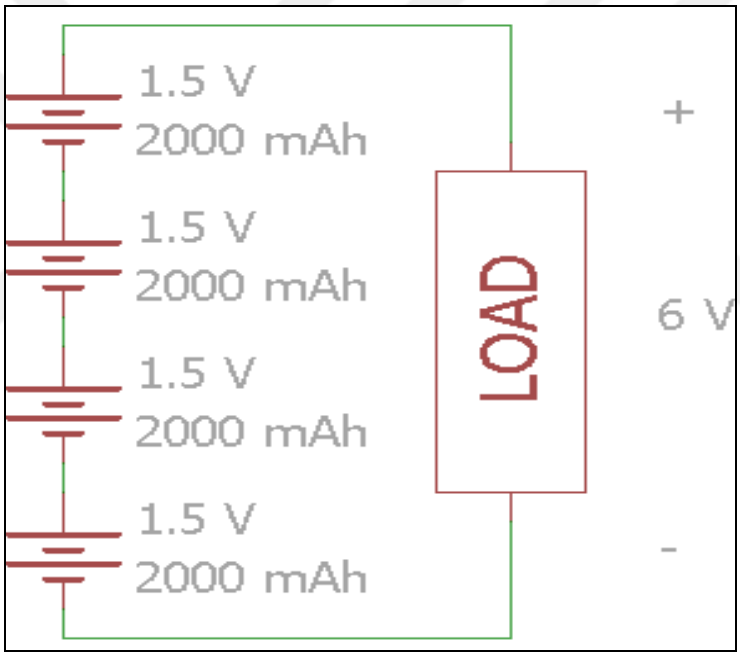

Figure 3.2. Connection of cells in series

3.3.1.4. Parallel

In order to increase the capacity cells must have been added in parallel providing enough single cell voltage. That all the cells should have the same nominal voltage and same charge level is very important. Any voltage differences causes short circuit and could occur causing possibly fire and overheating. Figure

3.3 shows connection of four 1.5 V cells in parallel. The voltage during the load is 1.5 V, while the capacity rises to 8000 mAh totally.

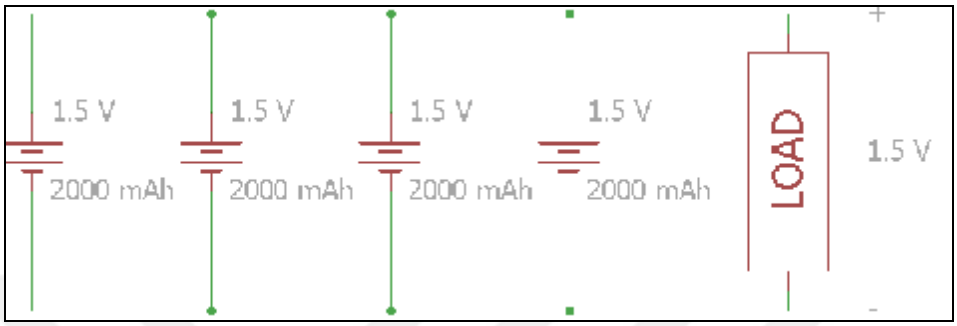

Figure 3.3. Connection of cells in parallel

3.3.1.5. Series and Parallel

In order to raise capacity and voltage simultaneously, combining of parallel and series batteries must be used. Figure 3.4 shows the total voltage during the load is 3V, and the total capacity is 4000 mAh.

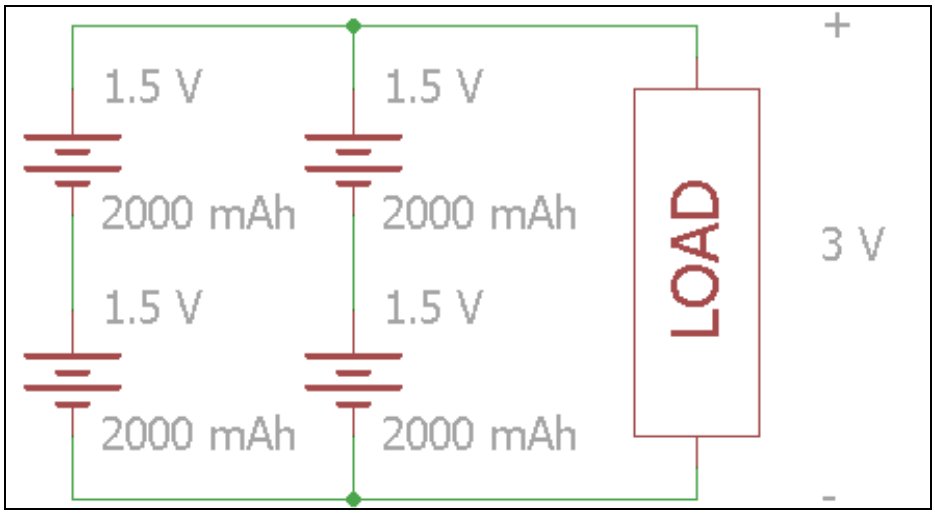

Figure 3.4. Connection of cells in series and parallel

In this study prismatic polymer li-ion battery cell is used because of its lightweight and high capacity. Figure 3.5 shows perspective view of a single prismatic polymer li-ion battery cell.

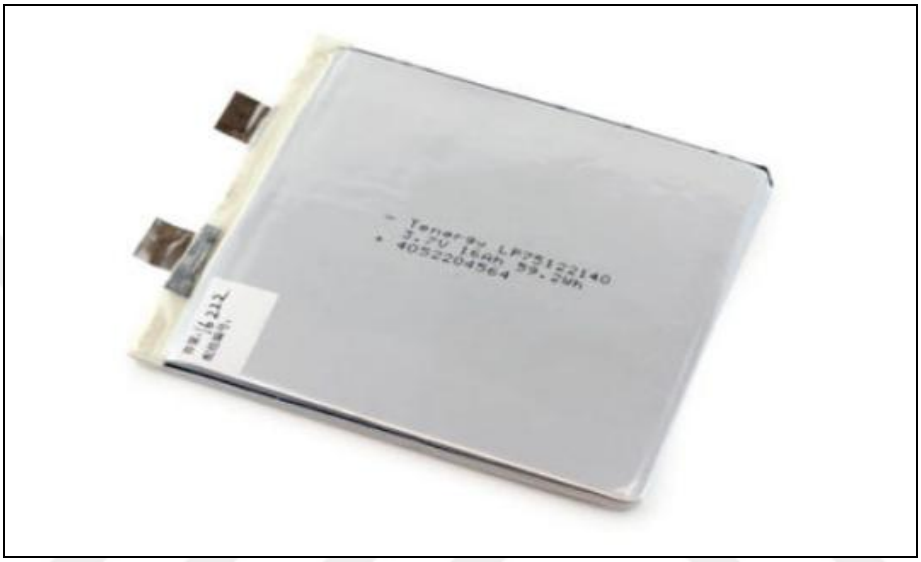

Figure 3.5. Prismatic polymer li-ion battery cell 3.7 V 16 Ah (Anonymous, 2018d)

Technical spesificiations of li-ion polymer battery cell is given with Table 3.3.

Table 3.3. Technical specifications of battery cell

Prismatic Polymer Li-Ion Battery, 16000mAh (80122140)	
Battery Chemistry	Polymer Li-Ion
Capacity	16000mAh
Model	80122140
Max Charging Current	1C
Max Discharging Current	2C
Weight	approx. 310g
Dimension	142mm x 124 mm x 7.6 mm

3.3.1.6. Grouping of Battery Cells

As mentioned below, the motor used in this study has a voltage specification of 72 Volts. In order to ensure compatibility between motor and batteries, their voltage values must be very close when connect each other. Therefore, it is necessary to add battery cells both in parallel and in serial to obtain a voltage 72V about. Figure 3.6 shows connection of cells in series and parallel in order to achieve 74V and 352 Ah capacities.

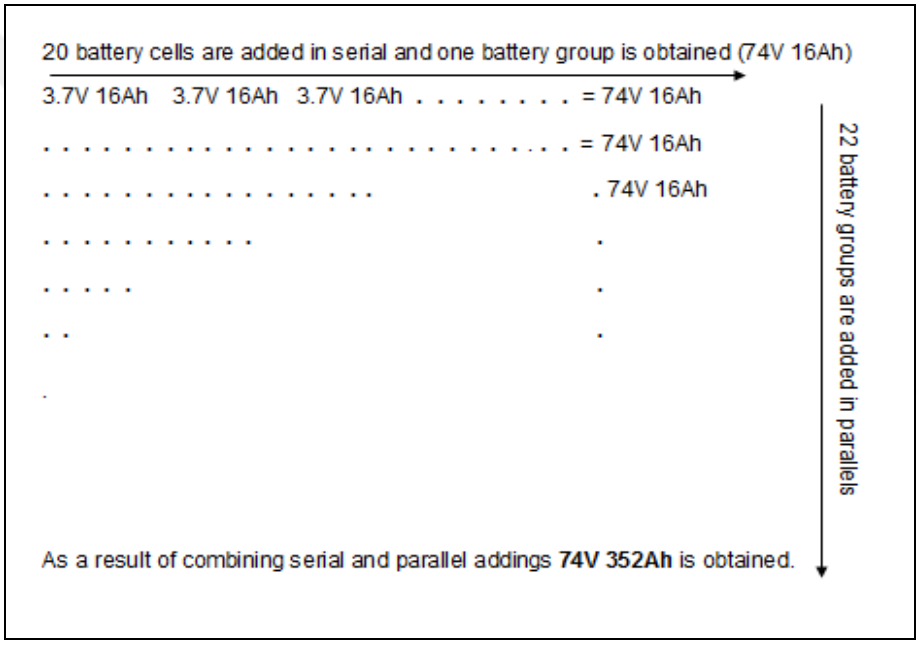

Figure 3.6. Combine connection of battery cells in series and parallel

3.3.2. Motor Basics

The purpose of a motor is to convert electricity to mechanical power in order to obtain rotary motion. The input and output parameters of a motor is illustrated in Figure3.7. The input electrical power can be in different forms of, AC line voltage, rectified AC line voltage, a DC battery or a wide array of control mechanism. The

input power can be frequency, amps and volts. The output power is the torque response and motor speed needed to fulfill the task of driving the system.

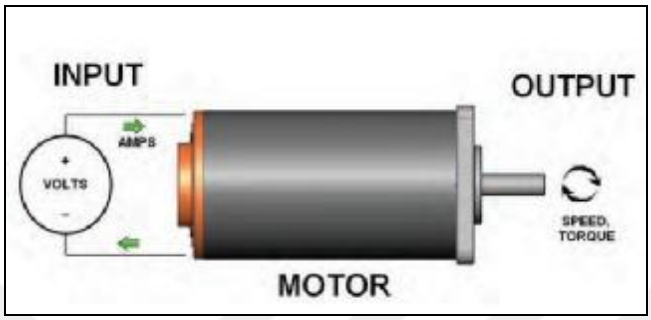

Figure 3.7. Motor functions: input, output (Groschopp, 2018)

3.3.3. Motor Types

There are four specific motor types that can be selected during the engine selection process. Each motor type will be presented in necessary level of details. The explanation of Brushless DC motors (BLDC), Universal (UM), AC Induction and Permanent Magnet DC (PMDC) are covered for the motor characteristics, construction, advantages and disadvantages.

3.3.3.1. Universal Motors

There are two features that distinguish Universal Motor (UM) from other motor types. First one is motor running criteria. DC and AC power supply can start motor separately. That is why it derives the name Universal. Second, the Universal motor is suitable on running with high speeds, greater than other types of motor (Groschopp, 2018).

Figure 3.8. Universal motor (Groschopp, 2018)

Universal motors operate on AC and DC power, their efficiency is between 55% and 70% due to motor dimensions. Frequently, the first advantage of preferring the UM is its huge density of power. It is common for the UM to have over twice the continuous output power of an AC Induction motor of the similar size. The huge power density of a UM ends up with high speed and generated fan cooling effects. Because of this high density of power, motor is a little noisy when compared other types of motor. If a Universal motor runs under 100 volts efficiency of the motor can be rather low (Groschopp, 2018).

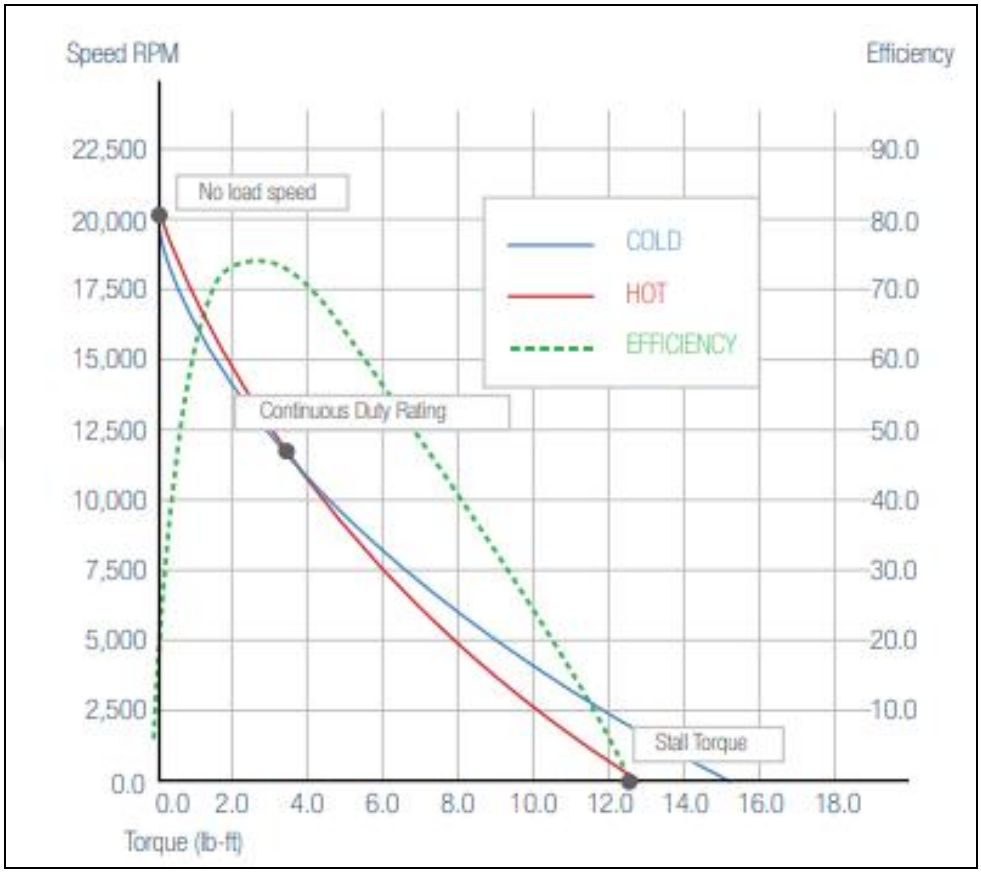

Figure 3.9. Torque, efficiency and speed curves for a UM (Groschopp, 2018)

When looking at performance curve for a UM (Figure 3.9) no load speed that instantly decrease as extra load and current are applied. The form of the Universal Motor curve is as a result of the additional field magnetic created as current movement through the windings rises. Observe the changes in performance during temperature of motor changes. For a definite torque point, the motor will start a little slower as it heats up. Finally, observe the motor's efficiency curve, the green dashed line. With ideal conditions, efficiency of motor will peak round the maximum torque (Groschopp, 2018).

3.3.3.2. Permanent Magnet DC Motors

The Permanent Magnet DC motor (Figure 3.10), like the Universal motor, has a wound armature as long as commutation through the commutator and brushes. PMDC motors use a fixed strength, permanent magnet field while UM motors have a wound field that varies in strength with the current draw of the motor. The stationary field strength yields a motor with linear form speed-torque curve, superior starting torque and lower unloads speeds. As it starts only on DC voltage, the PMDC motor needs of a rectifier or a control to be performed in a system compatible with AC line voltage (Groschopp, 2018).

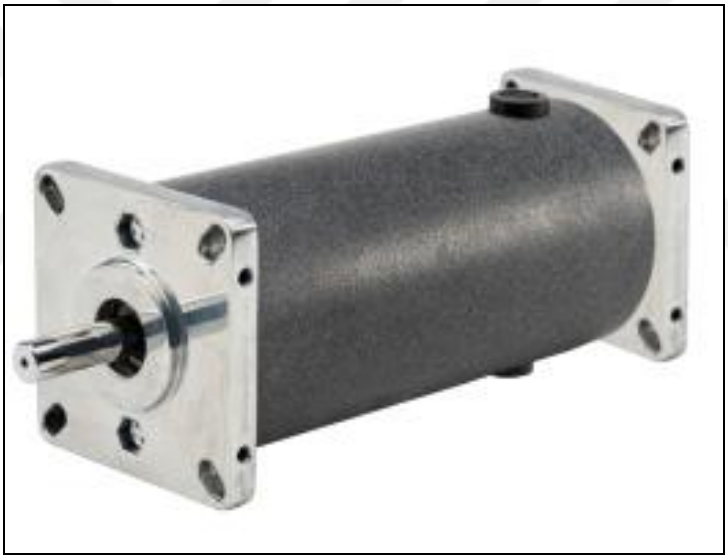

Figure 3.10. Permanent magnet DC motor (Groschopp, 2018)

A benefit of the PM motor is the lower performing speeds, making them ideal for allowing for more silent perform and use with gear reducers. Nevertheless, compared to a equivalently dimensioned UM motor, the power density of a PM motor is not as huge (Groschopp, 2018).

The linear speed-torque curve of PMDC motor is represented in Figure 3.11. This linearity makes it easier to check the motor torque output by easily monitoring

the current draw. Furthermore, the PMDC motor has a high starting torque and low unload speed. Looked at the hot motor curve, observe that as the motor temperature is increased, the unload speed is rising and the stall torque is diminished. This is because of the effect that heat has on the magnets. As the motor get cold, the speed will become normal. The efficiency curve is look like in shape to the Universal Motor (Groschopp, 2018).

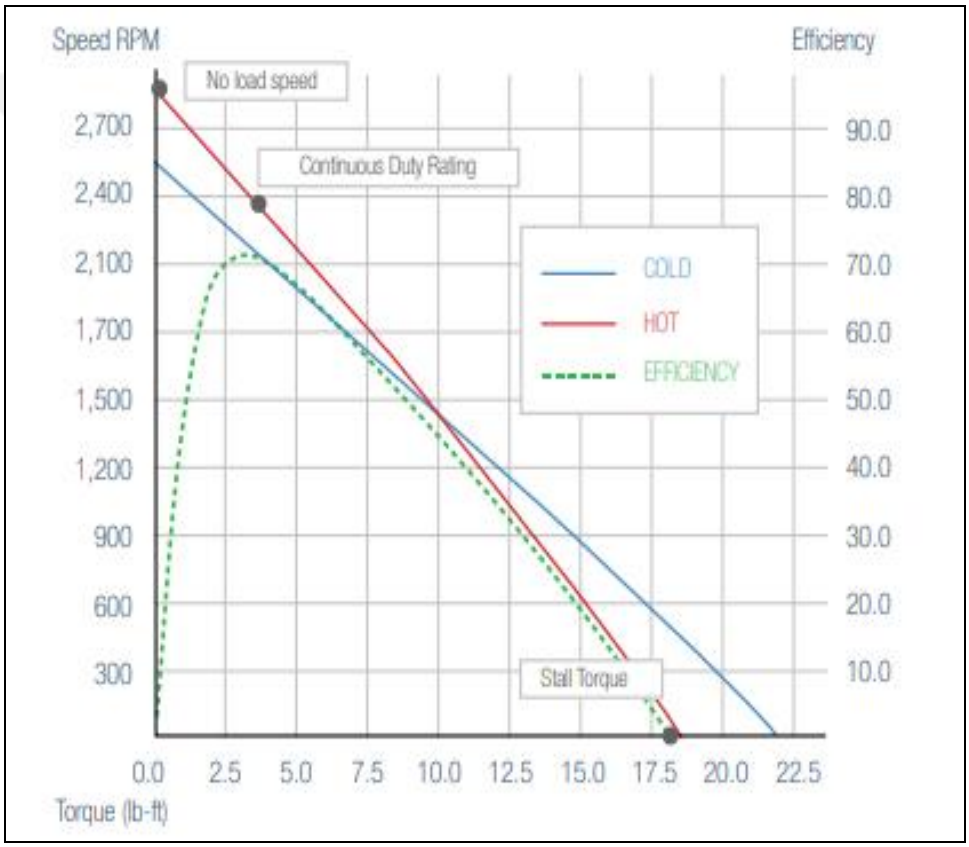

Figure 3.11. Torque, speed and efficiency curves of a PMDC motor (Groschopp, 2018)

3.3.3.3. AC Induction Motors

Construction and functions of the AC Induction Motor is different from the UM and PMDC motor. The brushes that perform the commutation and the

elimination of a wound armature are the main differences. The AC motor constructed from a cast rotor and wound stator. The rotor has a very easy construction, consisting of a shaft, cast aluminum, and laminations. While the construction of AC Induction Motor is different than the PMDC and UM motors, the idea is the same: A magnetic field is created and rotates about the motor through a process which is called commutation.

Figure 3.12. AC motor (Groschopp, 2018)

The AC Induction Motor can perform either a three phase or a single phase AC source of power. The motor output speed is fairly constant and is related with number of poles and the input voltage frequency. Contrary on a UM and PMDC motor, the input voltage value does not change the speed, only the input source frequency. That it does not have common wear components such as commutators and brushes is first benefit of an AC Induction Motor. The lack of these parts allows for low maintenance and better life potential. The AC induction motor life is generally restrained by the bearings (Groschopp, 2018).

Figure 3.13 illustrates a typical curve performance of three-phase AC induction motor. This curve is relatively linear till the downfall torque is reached. After downfall, the torque decreases sharply. Then the motor at higher temperatures leads to slow output speeds for a given conditions. The relevance of the hot and cold motor curves similar the Universal torque.

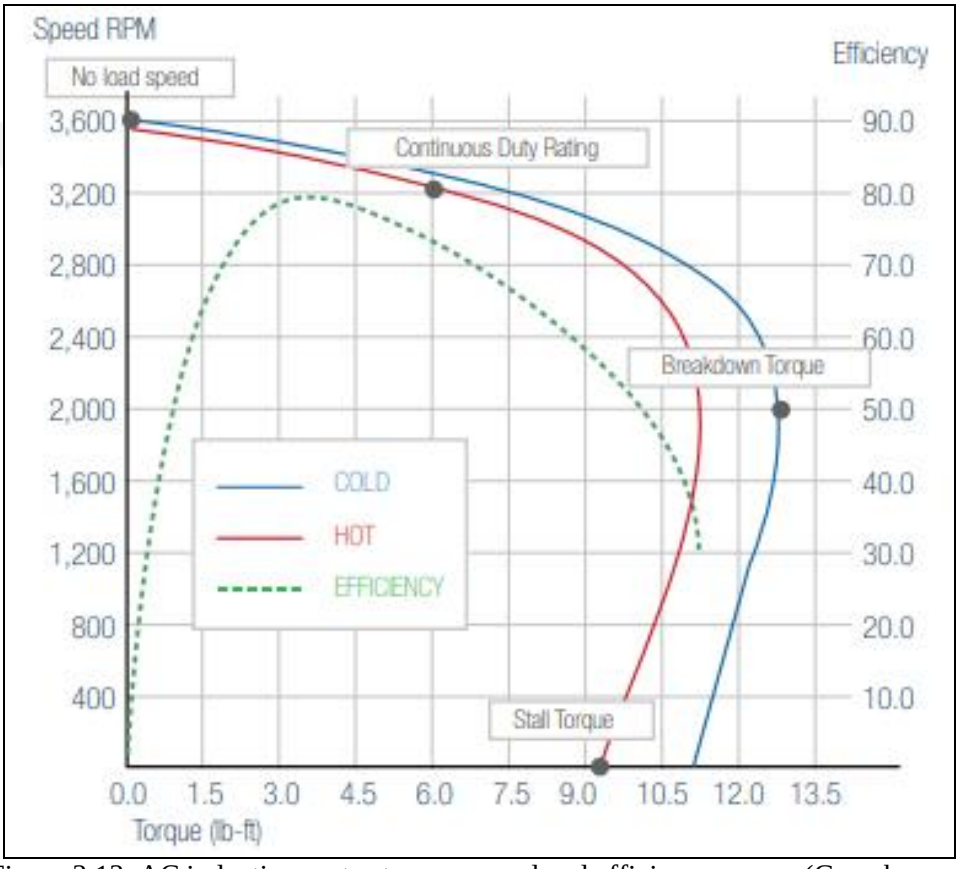

Figure 3.13. AC induction motor torque, speed and efficiency curves (Groschopp, 2018)

3.3.3.4. Brushless DC Motors

Brushless DC (BLDC) and AC Motor stator construction is similar. The rotor consists of a steel hub wrapped including permanent magnets

Figure 3.14. Brushless DC motor (Groschopp, 2018)

The performance of a PMDC motor and a BLDC motor are very similar. PMDC motor's speed-torque curve has a very linear progression. Although, the curve performance of PMDC and BLDC looks similar, the power density and efficiency of the BLDC motor are greater than the PMDC. BLDC motors are more attractive for certain applications as the size of control electronics and price are reduced (Groschopp, 2018).

Construction of PMDC integrates the low maintenance and long life advantages of AC induction motor. Power density of BLDC motor is second only to the UM.

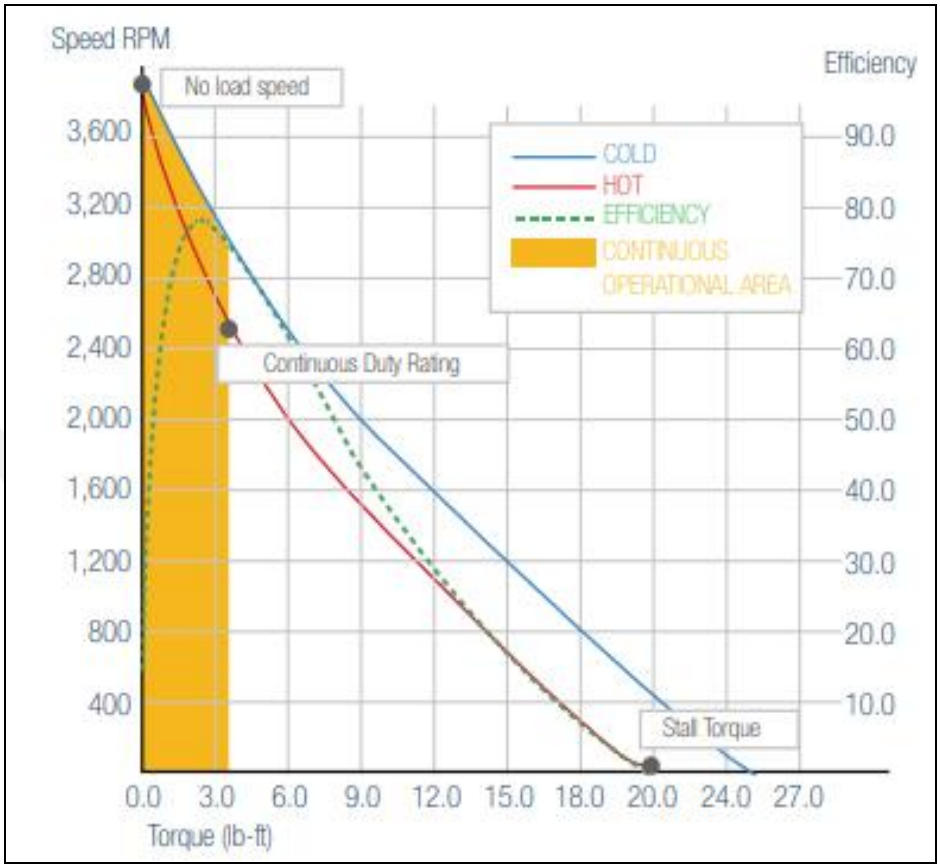

Figure 3.15. BLDC motor torque, speed and efficiency curves (Groschopp, 2018)

The speed-torque of BLDC motor curve represented in Figure 3.15 which is so similar PM motor's curve. The curve symbolizes performance of motor with fully voltage, except control of speed regulation. As a control is generally preferred with a BLDC motor, there is application of a standard motor winding flexibility (Groschopp, 2018).

3.3.4. Motor Torque

A motor must generate enough rotation motion to run a load and to hold it operating with usual conditions. The manufacturer construct an electric motor to generate enough torque for varied of loads.

3.3.5. Technical Specification of Motor Selected for EV

In this study, in order to drive the EV, M102 DC motor is preferred. Table 3.4 and 3.5 show some technical specifications of EV motor like voltage, current, torque, speed, power, efficiency, weight etc.

Figure 3.16. M102 DC electric motor 72 Volt

As shown Table 3.4 maximum efficiency (90%) of motor can obtain where the torque value is 42.38 Nm. This value is important for range calculation. In order to extend the range of EV, motor should be light as possible as. Another criteria is efficiency which is directly affects the range of EV.

Table 3.4. Technical specification of M102 DC motor

DC Voltage	Current (Amps)	Speed (RPM)	Torque NM (Ft Lbs)	Power KW (HP)	Efficiency (%)
	300	1938.4	90.25 (66.5)	18.3 (24.5)	82
	250	2119.2	70.23 (51.8)	15.6 (20.9)	84
	220	2240	59 (43.5)	13.8 (18.5)	86
	205	2329.6	54.11 (39.9)	13.2 (17.7)	88
	180	2472.8	44.8 (33)	11.6 (15.5)	88
72	170	2560	42.38 (31.3)	11.4 (15.3)	90

In order to extend range of EV, motor must be light as possible as. Another important criteria efficiency of mechanical parts especially motor efficiency.

Table 3.5. Technical specification of M102 DC motor

Model	M102 Motor
Type	DC Motor
Max Power	18.3 kW @ 1938.4 rpm
Max Torque	90.25 Nm @ 1938.4 rpm
Voltage	72 V
Max Efficiency	90%
Weight	86.18 kg
Motor Diameter	254 mm

Electric motor selection for electric vehicles is one of the most important issue. The choice of the right motor and the power calculation of the motor is determined by weight of the vehicle, the geographical conditions of the area vehicle used and some another criteria.

3.3.6. Gearbox

One of the biggest differences between electric cars and their conventional counterparts has to do with the drivetrain. An internal combustion vehicle has a multi-speed gearbox with numerous ratios; nearly every electric car has a single-speed transmission.

Figure 3.17. Gearbox

The specifications of the gearbox that is used in the study are as listed in Table 3.6.

Table 3.6. Technical specifications of the gearbox

Brand	Borg Warner
Model	31-03 e Gear drive
Speeds	Single
Efficiency	97%
Available reduction ratios	6.54,7.17,8.00,8.28,8.76,9.07
Lubrication	Splash
Rated input torque	200 Nm
Max input speed	14000 rpm
Weight	28 kg
Center distance	210 mm

3.3.7. Material For Platform Structure of EV

In order to reduce the weight of vehicle body or chassis, aluminum is used frequently due to its lightening. Despite being soft metal, some certain aluminum alloys have high strength –weight ratios.

An aluminum alloy is a chemical composition of pure aluminum and some other elements. They are added to pure aluminum in order to improve its

mechanical properties, firstly to improve its strength. Some other elements include manganese iron, copper, silicon, magnesium, zinc and manganese. These added elements divided different groups due to alloying elements. One example is 6xxx series. This series are highly formable, versatile, weldable, heat treatable and have perfect wear resistance. Alloys with this series include magnesium and silicon to form magnesium silicide within the alloy. Alloy 6061 is the most widely preferred alloy in this series and is often used in marine and truck frames. Al-6061 was used for EV chassis material in this study.

The properties of materials are given in Table 3.7. Properties of materials were accessed from MatWeb for St- 37 Steel and Al-6061. Advanced high strength steel, Usibor 1500 material properties were taken from Arcelormittal product catalog.

Table 3.7. Material properties of St- 37 steel, AL-6061 and Usibor 1500

Materials	Density (kg/m^3)	Elastic Modulus (GPa)	Poisson's Ratio	Tensile Strength, Yield (MPa)	Tensile Strength, Ultimate (MPa)
St-37	7860	200	0,29	205	370
Al-6061 T6	2700	68,9	0,33	276	310
Usibor®	7860	205	0,29	1100	1500

3.3.8. Material for Monocoque Structure of EV

Özarslan (2015) manufactured a light material consist of unidirectional-300 g/m2 carbon fiber fabrics and laminating resin MGS L160 epoxy in his Msc. Thesis (Özarslan 2015) presented in Table 3.8.

Table 3.8. Mechanical and physical properties of materials that are used

Materials	Tensile strength (MPa)	Young's modulus (GPa)	Density (g/cm3)	Diameter (μm)
Carbon Fiber	4900	240	1,79	7
Epoxy	70-80	3,2-3,5	1,13-1,17	-

After production of specimen of material, Özarslan (2015) performed a number of tests to determine the mechanical properties of the material; tensile test, flexural test, compression test, losipescu shear test, open-hole compression test. Finally, mechanical properties of carbon fiber reinforced-epoxy laminated composite material was defined as shown in Table 3.9 (Özarslan 2015).

Table 3.9. Mechanical properties of carbon fiber-epoxy laminated composite

Material Properties	Symbol	Units	Values
Density	ρ_C	g/cm^3	1,54
Fiber volume fraction	V_f	%	55
Longitudinal modulus	E_{11}	GPa	137
Transverse modulus	E_{22}	GPa	10
Axial Poisson's ratio	v_{12}	-	0,3
Transverse Poisson's ratio	v_{21}	-	0,022
Longitudinal tension strength	X_t	MPa	1192
Transverse tension strength	Y_t	MPa	21
Longitudinal flexural strength	σ^L_f	MPa	576,507
Transverse flexural strength	σ^L_f	MPa	39,821
Longitudinal flexural modulus	E^L_B	GPa	95,319
Transverse flexural modulus	E^T_B	GPa	6,539
Longitudinal compression strength	Xc	MPa	305,28
Transverse compression strength	Yc	MPa	64,7
Longitudinal compression modulus	E^C_{11}	MPa	
Transverse compression modulus	E^C_{22}	MPa	
Shear strength	S_{12}	MPa	59,45
Shear modulus	G_{12}	MPa	4705
Open hole compressive strength	F^{ohcu}	MPa	147

4. NUMERICAL METHOD AND SYSTEM DESIGN

4.1. Computer Software

In this study, FEM, CAD and MATLAB/SIMULINK software are preferred to make decision of the design and material. In this chapter basic information about these technologies are presented.

4.1.1. Computer Aided Design (CAD)

Computer aided design (CAD) is a technique using computer programs to perform in the modeling, optimization, modification or analysis of a design. A typical CAD software is composed of the computer programs to perform computer graphics system and application programs to facilitate the engineering characteristics of the user. CAD/ CAM products are used to enhance creativity of a designer, augment the quality of design, enhance communications through documentation, and create a database for manufacturing (Sarcar et al., 2008).

In 1969, Dassault Aviation, the French aircraft manufacturer, produced an interactive chart program for the establishment of their activities. Developed over time the software is unique software that can respond to three-dimensional geometric definitions updated. The presented work is developed by using catia.

Catia is a solid modeling computer-aided design software program that runs on Microsoft Windows.

4.1.2. Finite Element Method (FEM)

The Finite Element Method (FEM) was first used for stress analysis problem solving and then it has been applied to many other applications such as fluid flow analysis, thermal analysis and piezoelectric analysis. Fundamentally, the analyst search to conclude the distribution of certain field variable like the temperature or heat flux in thermal analysis, the displacement in stress analysis, the electrical charge in electrical analysis, and so on. The FEM is a mathematical method aim to

seek an approximated result of the distribution of problem field variables that is difficult to achieve analytically. It is accomplished by separating the problem domain into various elements, as represented in Figures 4.1. Common known physical laws are implemented to each divided small element, each with a very simple geometry. Figure 4.2 represents the finite element estimates for a uni-dimensional case graphically. (Liu and Quek, 2003).

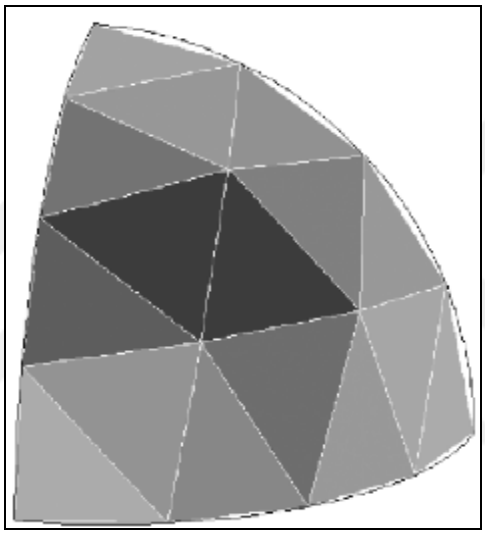

Figure 4.1. The quarter spherical section is divided into several shell elements (Liu and Quek, 2003)

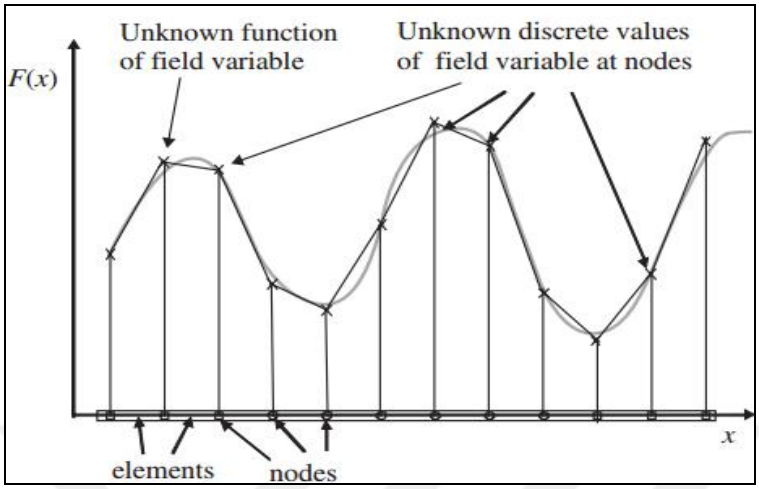

Figure 4.2. FEM approach for a uni-dimensional case

A continuous function is approached by using linear partial functions in each element (Liu and Quek, 2003).

4.1.3. Matlab/Simulink

Simulink is a plug-in product to the MATLAB. It is enable interactive, graphical environment for dynamic systems simulating, modeling and analyzing. It provides quick development of virtual models to investigate design concepts with minimal effort with more details. For modeling, simulink enables a graphical user interface (GUI) for constructs designs as block diagrams. It involves a broad library of common blocks to be preferred to create visual models of systems with drag-and-drop mouse operations. The user can design an “up-and-running” model that would otherwise need hours to create in the laboratory conditions. It supports nonlinear and linear systems, modeled in sampled time, continuous-time, or compose of them. Simulink is combined with MATLAB and data transfer can be easily between them (Samuel at all, 1996).

4.2. Design

The design is a long and time consuming process. Existing ideas help to design a new idea. The idea is then worked out in consideration of its commercial success and given form and form as drawings.

Generally component design includes many steps in it. Firstly, the design must be made in suitable software and it must be transformed into a 3D model. This 3D model must be exported into analyzing platform where it is thermally or structurally analyzed to maintain the requirements. Different steps involved in designing a component are:

- Part drawing
- Modeling
- Structural analysis

The chassis and body of EV's divided in to individual components and each component is drawn and modeled and finally assembly of these components is structurally analyzed by using software and its procedure is explained as below.

4.2.1. Part Drawing

Generally the part drawings are drawn to have a clear idea of the model to be produced. Parts required for assembly are drawn separately with certain constraints. these drawn parts are assembled in the assembly module.

4.2.2. Modeling

Modeling is the method of building a numerical representation of any three-dimensional (3D) surface of object by using specific software. The output is called a 3D model. Wire frame modeling, surface modeling and solid modeling are various types of modeling techniques used in practice.

4.2.2.1. Battery Pack

The chassis is designed to hold four battery packs, two on the right and two on the left side of the vehicle. Each battery packs includes 112 battery cells which connected each other in serial or parallel ways. Dimension of battery pack is 574 x 496 x 7,6 mm.

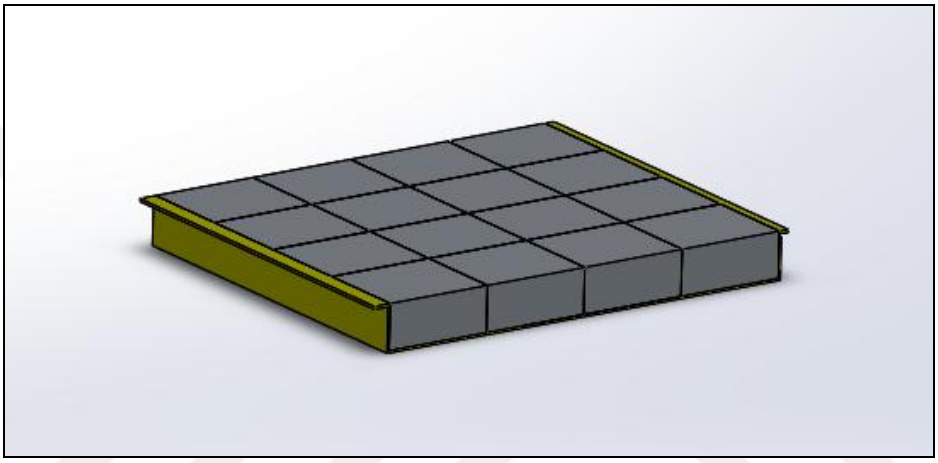

Figure 4.3. Battery pack with battery cells

It has edge structures that will overlay chassis profiles. This system provides a battery module that battery pack can quickly slide into battery module compartment on the EV. Also system has a locking device which maintain battery modules within the battery module compartment.

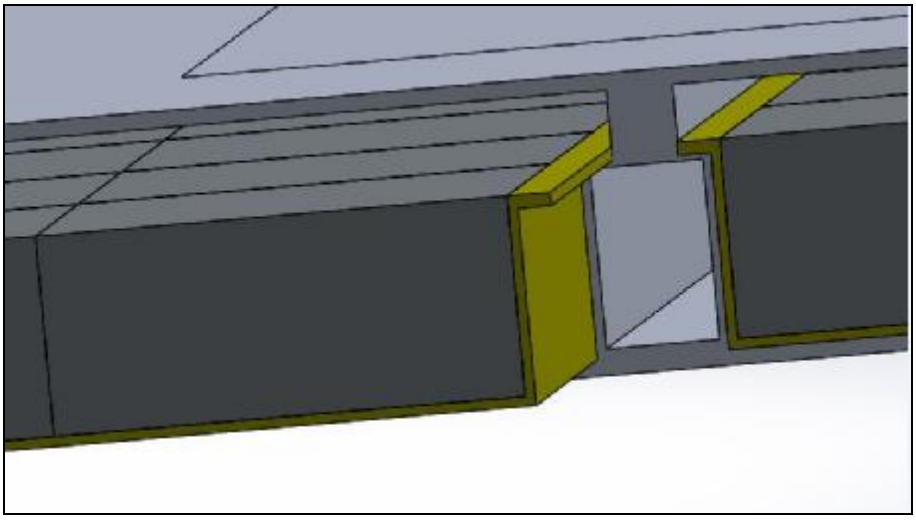

Figure 4.4. Sliding mechanism of battery packs

4.2.2.2. Chassis of EV

The chassis is composing of a mixture of the monocoque and the platform frame types. Lower chassis type is a platform structure yet upper chassis is a monocoque structure. It is modeled in Catia V5 R20 software program. Platform chassis frame is designed aluminum and monocoque chassis is designed carbon fiber-epoxy composite material. Dimensions of the platform chassis are 2062 mm in length, 1118 mm in width and chassis weighs 147,5 kg, as shown in Figure 4.5.

The dimensions of the monocoque chassis are 2375 mm in length, 1309 mm in width, 1100 mm in height and chassis weighs 85,82 kg, as shown in Figure 4.6.

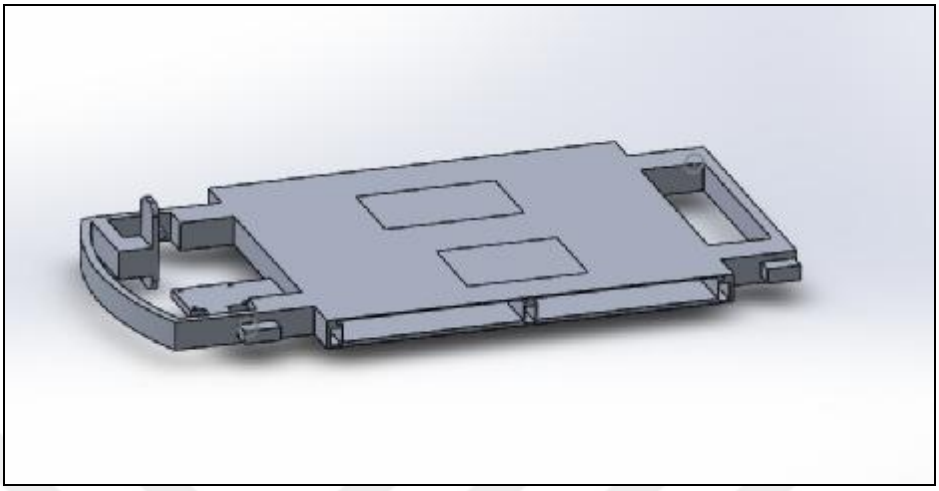

Figure 4.5. 3D model of platform structure

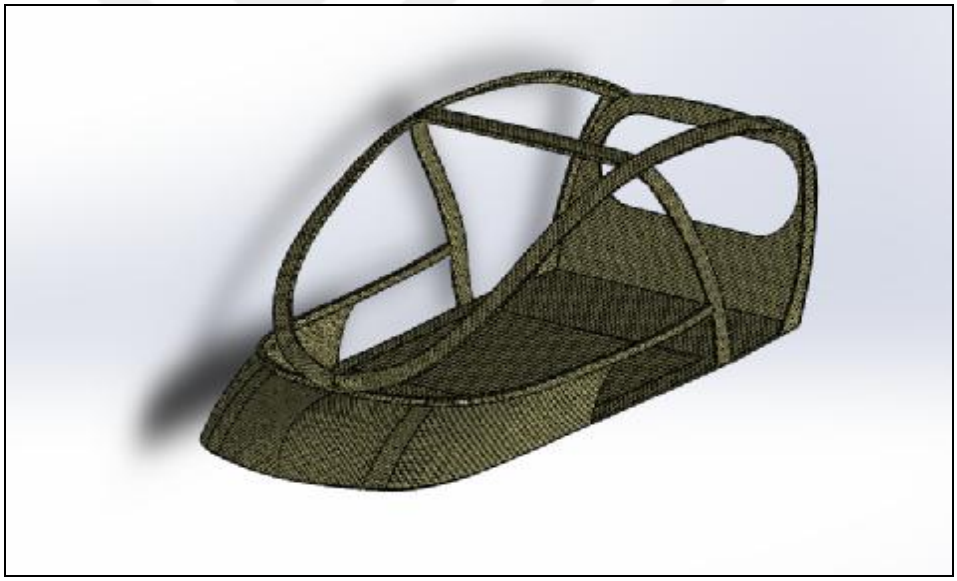

Figure 4.6. 3D model of monocoque structure

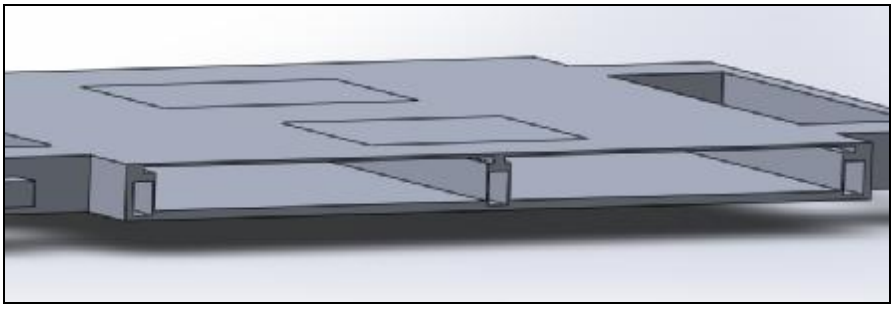

Figure 4.7. Side view of battery module compartment

EV also involves an access door integrated on chassis, wherein the access door turns from closing position to an open position uncover the battery module compartment.

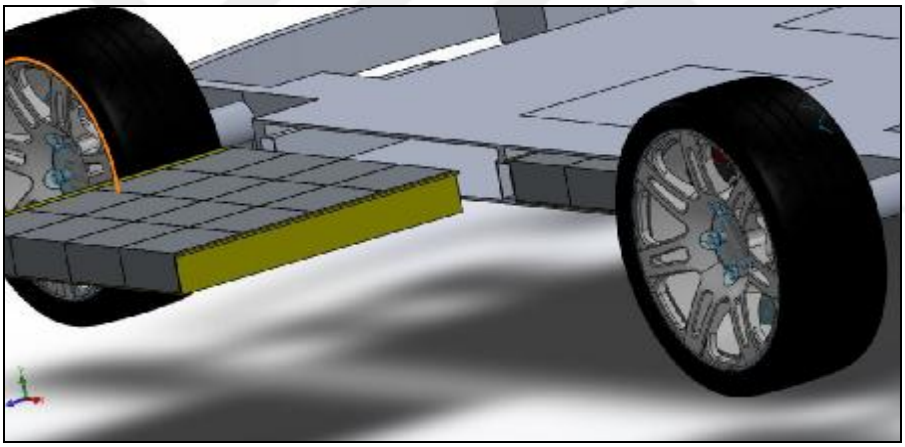

Figure 4.8. Perspective view battery module removed

EV includes portable battery packs to minimize the place that needed on its own.

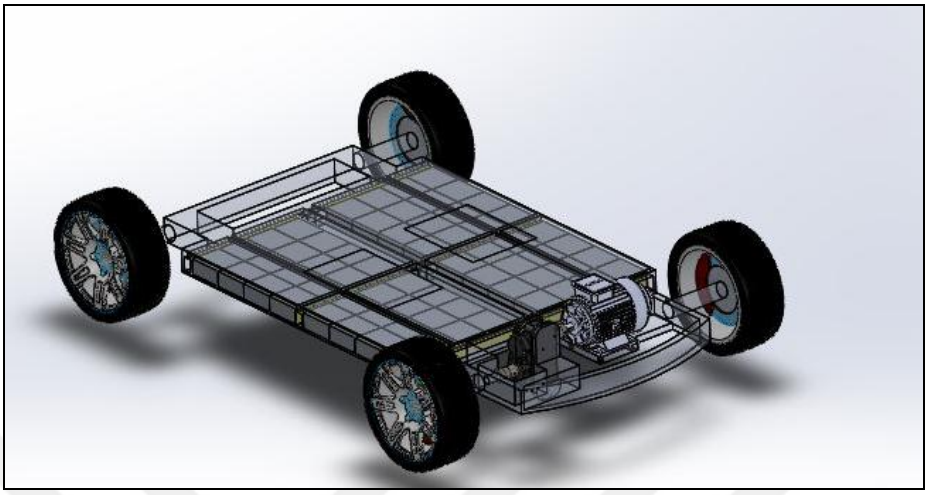

Figure 4.9. Perspective view the battery module inserted therein

As illustrated in Figures 4.7, 4.8 and 4.9 The EV includes a chassis that defines a battery module compartment for receiving a battery module. The EV also includes an access door to the chassis to provide access to the battery module compartment.

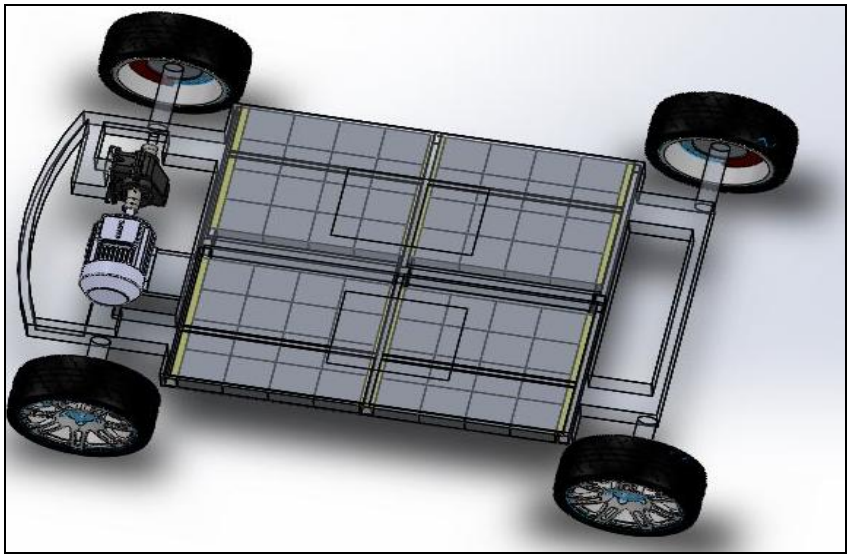

Figure 4.10. Positions of motor, gearbox and battery packs

If the electric vehicle is double-pulled or single-pulled or if the car's drive system supply with a single electric motor is one of the factors affecting the design of the chassis. In the design, the drive is planned with a single electric motor to the front of the vehicle via the power shaft.

4.2.3. Assembly

The parts that are created in part module are imported to assembly module and by using ‘insert components’ command and all these parts are mated together to form the required assembly. The different views of assembly and the drawing created in Catia V5 R20 are as shown below.

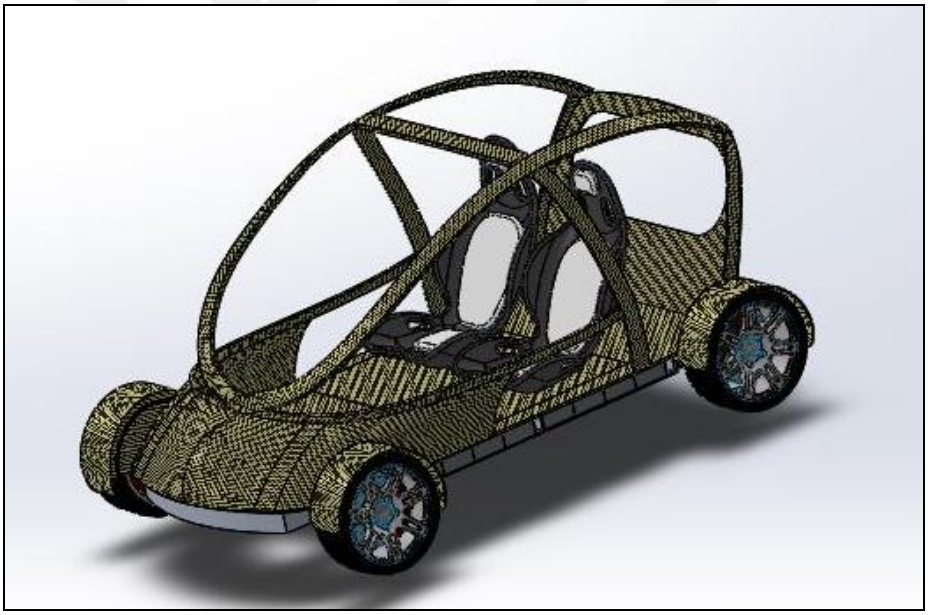

Figure 4.11. Perspective view of assembly

It is easy remove the battery pack and insert full-charged batttery pack in very short time in this EV model. As mentioned above, upper chassis and platform chassis have different materials. For upper chassis, carbon fiber composite is applied in order for lightweightining EV body. This is also important for extending

range of EV. As for platform chassis, AL6061 is used. This material is also a light weight material.

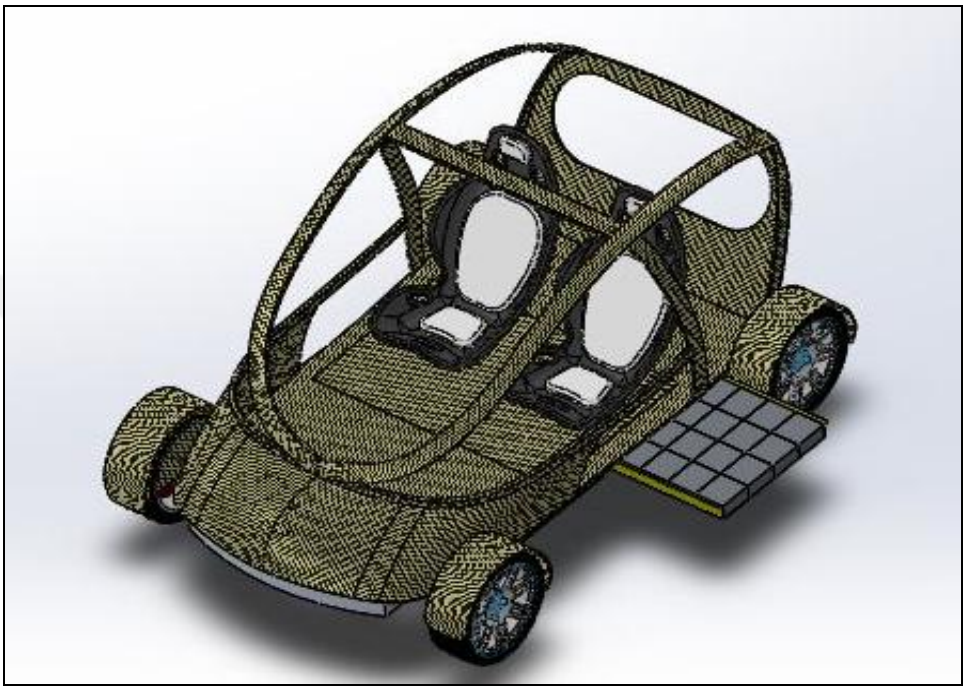

Figure 4.12. Perspective view of EV while removing battery pack

4.2.4. EV Model Physical Properties

EV model has two seater, DC motor, gearbox and battery groups. The range of an electric vehicle depends on the number and type of batteries used. The weight of battery groups is 150 kg. The wheelbase of electric vehicle is 1652 mm. Removing of batteries is possible with sliding drawers. Use of environmentalist and light motor characteristic and monocoque chassis made up of carbon fiber - epoxy composite material and platform chassis made up of aluminum alloy are the main reason to preferring for the cars of the future. Chassis weight of available electric vehicle is 147,5 kg for the platform structure, 86 kg for the monocoque structure.

4.2.5. Structural Analysis

In order to determine the physical structures load effects on the components, the structural analysis methodology is used. The outputs of the analysis are utilized to check a structure's life for use, generally record physical tests. Structural Analysis is very important of design engineering of structures. There are various steps that are to be followed in analyzing a component structurally. They are;

- Mesh Generation
- Fixed supports
- Application of loads
- Evaluating result

4.2.5.1. Mesh Generation

The process for generating a mesh compose of three common steps

- Set the element loaded
- Set mesh criteria (optional)
- Model meshing

As default mesh controls are suitable for many applications, there is no obligation to regulate mesh controls. FEA of EV model is calculated in catia simulation module by using a CAD representation of the physical model. CAD representation of the chassis is cut into small elements. Meshed model has 48244 solid elements and 90451 nodes. Meshed model is illustrated in Figure 4.13.

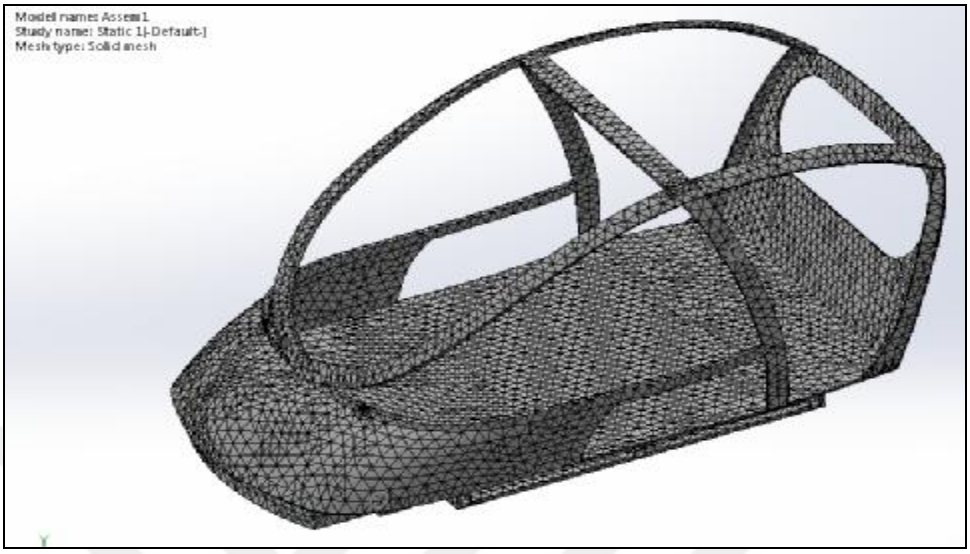

Figure 4.13. Meshed EV model

4.2.5.2. Fixed Supports

Wheel positions are selected for fixing supports on vehicle frame. Therefore, there are four fixing points on vehicle to be used in analysis.

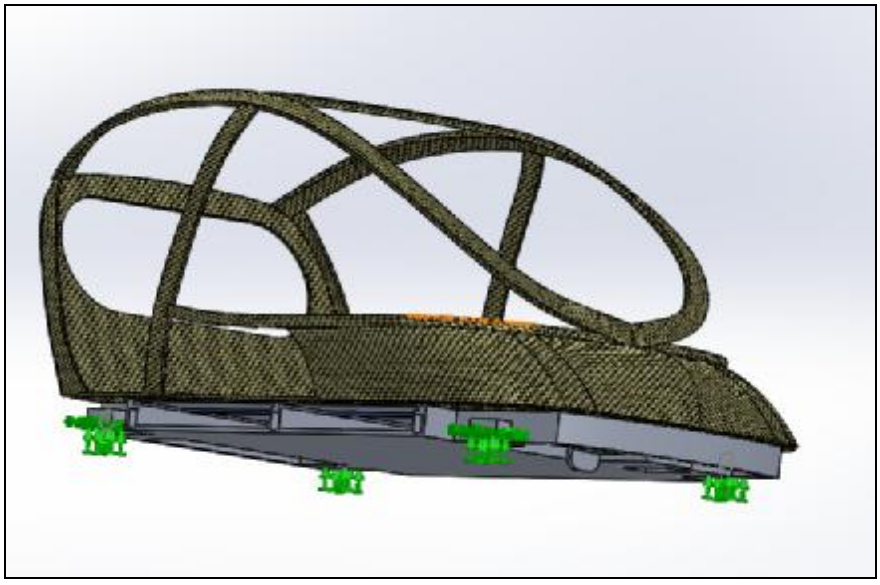

Figure 4.14. Perspective view of fixed supports

4.2.5.3. Loads Application

Main part of an model analysis is application of loads. There are various types of loads such Point Load, Uniformly Varying Load, Uniformly Distributed Load.

Table 4.1. Applied loads on the chassis

Load on the chassis	Weight (kg)
DC Motor	86,18
Gearbox	28
Driver and seat	90
Passenger and seat	90
Battery groups	150

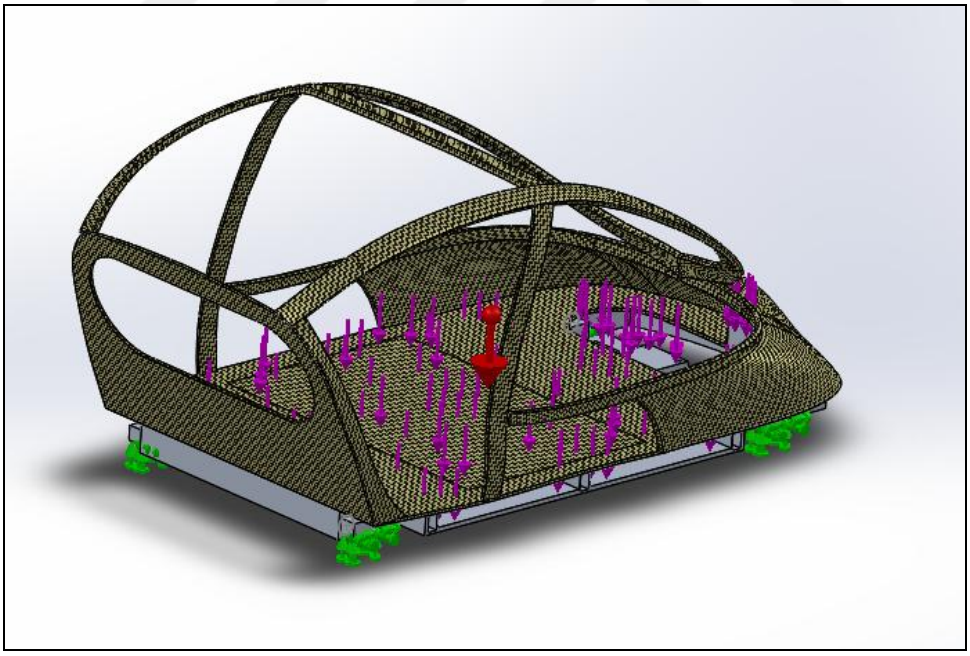

Figure 4.15. View of applying loads on chassis

Table 4.2. Boundary conditions of the chassis

Type of Boundry Conditions	Representation	Magnitude
	Own weight of the chassis	
Standard Earth Gravity	due to earth gravity	9806,6 mm/s^2
Fixed Support	Wishbone and suspension	-
Fixed Support	Wishbone and suspension	-
Fixed Support	Wishbone and suspension	-
Fixed Support	Wishbone and suspension	-
Force	Weight of DC motor	845 N
Force	Weight of gearbox	200 N
	Weight of driver,passenger	
Force	and 2 seats	1766N
Force	Weight of battery groups	1500N

4.2.5.4. Stress and Deformation

It is a physical amount that explain the internal forces that adjacent particles of a material apply one to another. For instance, while a rigid vertical rod is supporting a weight, each piece in the rod shrink the pieces instantly below and above it. There are different kinds of stresses developed in a par tor component. In this study, equivalent stress is considered to analysis of EV frame.

a) Equivalent stress: When an flexible material is exposed to forces in its three dimensions, the tension or stress will occur due to the bodystresses princible axis. The yield stress of the material should exceed these stress occured on material. Von Mises stress is significant criteria for design applications and engineers. This information gives idea to engineers about his design whether will fail or not.

b) Deformation: If an object is exposed to the forces, shape of this object may be changed permanently or temporarily as a result of applied force. This distortion in shape of object is called deformation. If the deformation of object is permanent, it is called failure or plastic deformations. If the deformation of object

is temporary, in this case it is called elastic deformation. When analyzing a material, if the material deforms elastically due to maximum loading limit so that the design is safe.

5. RESULT AND DISCUSSION

As mentioned earlier in the thesis, carbon fiber was used for the monocoque chassis and Al6061 material for the platform chassis. However, traditional chassis are generallt consist of stainless steel and aliminum alloy. In order to determine the differences of deformations and stresses of the EV chassis, materials were grouped as different versions. Table 5.1. shows four versions due to materials which are used.

Table 5.1. Material compositions used for studied versions

Chassis	Version 0	Version 1	Version 2	Version 3
Monocoque	Carbon fiber	AL6061	AL6061	ST-37
Platform	AL6061	ST-37	AL6061	ST-37

5.1. Stress and Deformations

5.1.1. Version 0

The Equivalent stress distribution of the assembly is as shown in Figure 5.1

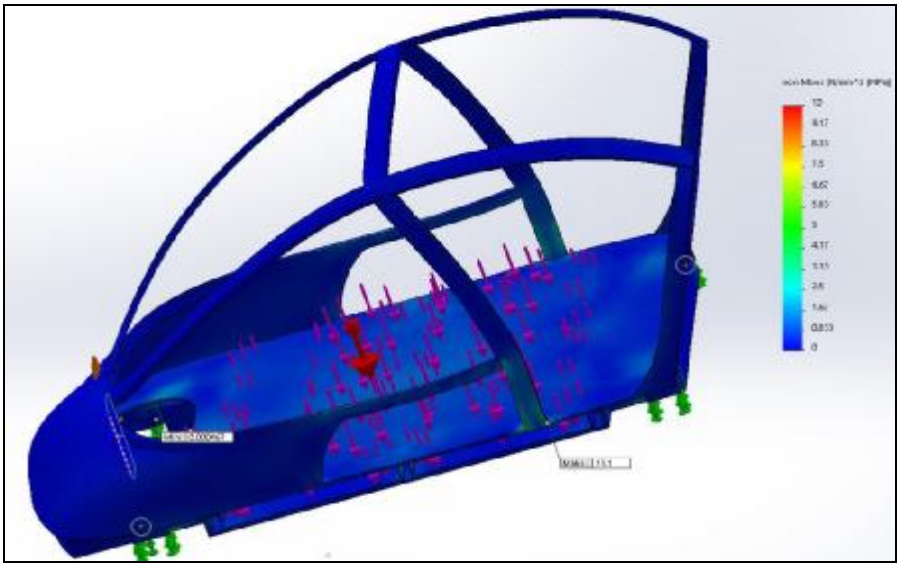

Figure 5.1. Von-Mises stress of the chassis

From Figure 5.1 it can be inferred that

MaximumEquivalent stress = 23.1 Mpa

Minimum Equivalent stress = 0.000467 Mpa

Results showed that maximum von-Mises stress of the design is 23.1 MPa and the value is far below the material's yield strength of 280 MPa. Maximum Von-Mises stress point as shown in Figure 5.1.

The deformation values obtained in Catia V5 R20 for assembly are as illustrated in Figure 5.2.

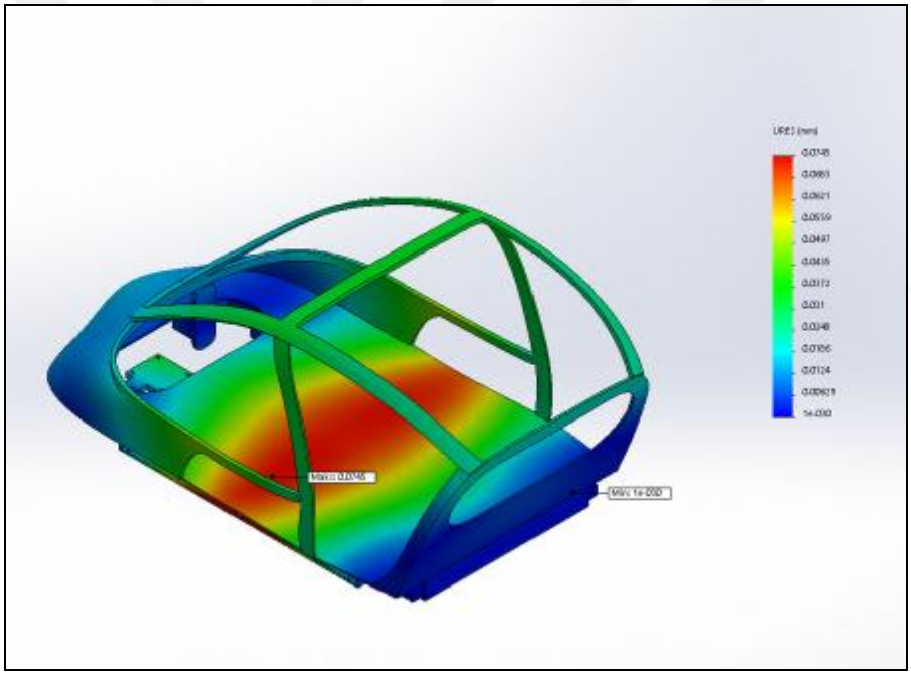

Figure 5.2. Total deformations of chassis

Maximum deformation = 0.0745mm

Minimum deformation = 1e-030 mm

Maximum deformation was observed in the center of driver cabin and battery packs region. However, value of maximum deformation (0.0745 mm) is very low when compared other automotive chassis deformations. The value demonstrates that chassis design and selected materails are very effective.

5.1.2. Version 1

The Equivalent stress distribution of the assembly is as shown in Figure 5.3.

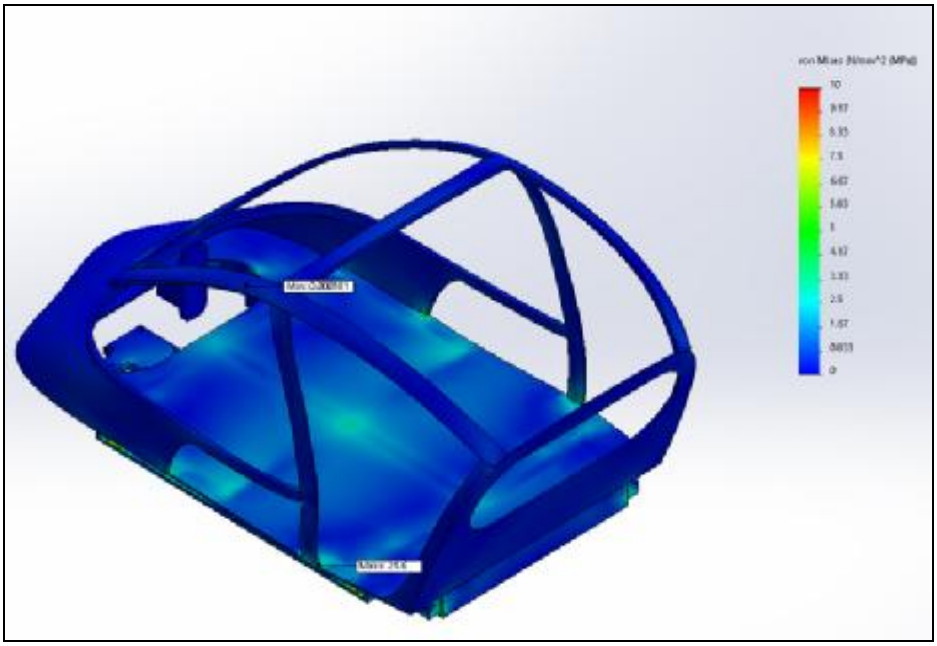

Figure 5.3. Von-Mises stress of the chassis

From Figure 5.3 it can be inferred that

Maximum Equivalent stress = 21.6 Mpa

Minimum Equivalent stress = 0.000181 Mpa

Results showed that maximum von-Mises stress of the design is 21.6 MPa and the value is far below the material's yield strength of 55.14 MPa. Maximum Von-Mises stress point as shown in Figure 5.3.

The deformation values obtained in Catia V5 R20 for version 1 are as illustrated in Figure 5.4.

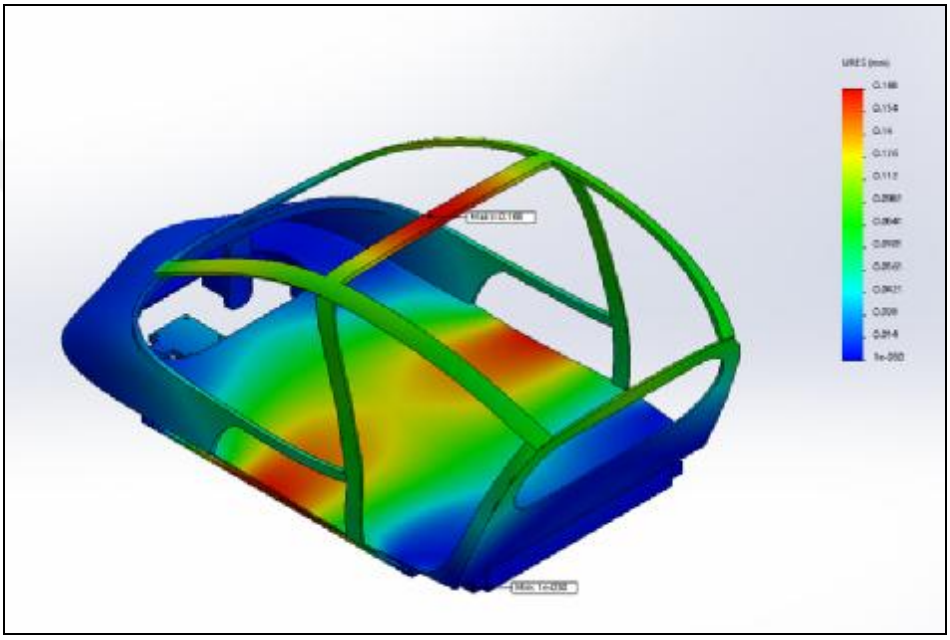

Figure 5.4. Total deformations of chassis

Maximum deformation = 0.168mm

Minimum deformation = 1e-030 mm

Maximum deformation is observed in the center of roof pillar.

5.1.3. Version 2

The Equivalent stress distribution of the assembly is as shown in Figure 5.5.

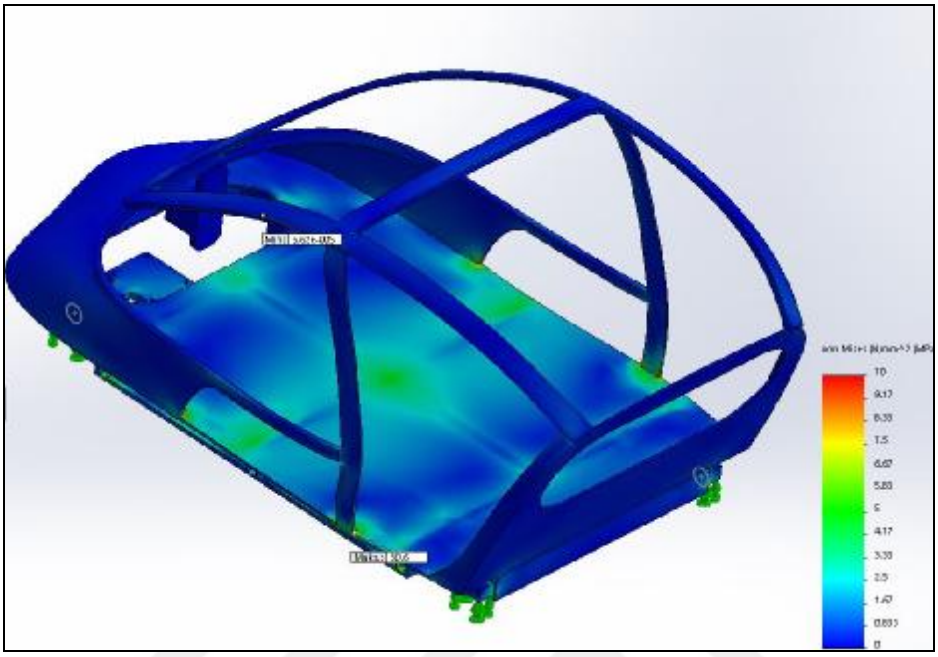

Figure 5.5. Von-Mises stress of the chassis

From Figure 5.5 it can be inferred that

Maximum Equivalent stress = 30.6 Mpa

Minimum Equivalent stress = 6.62e-005 Mpa

Results showed that maximum von-Mises stress of the design is 30.6 MPa and the value is not far below the material's yield strength of 55.14 MPa. Maximum Von-Mises stress point is shown in Figure 5.5.

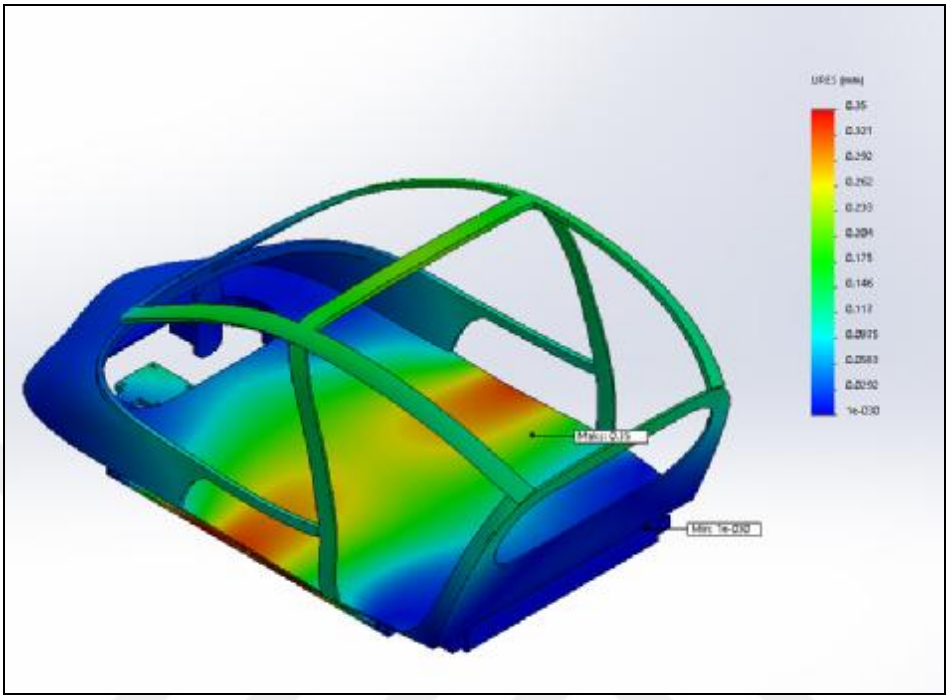

Figure 5.6. Total deformations of chassis

Maximum deformation = 0.35 mm

Minimum deformation = 1e-030 mm

Maximum deformation is observed in the center of driver cabin.

5.1.4. Version 3

The Equivalent stress distribution in the assembly is as shown in Figure 5.7.

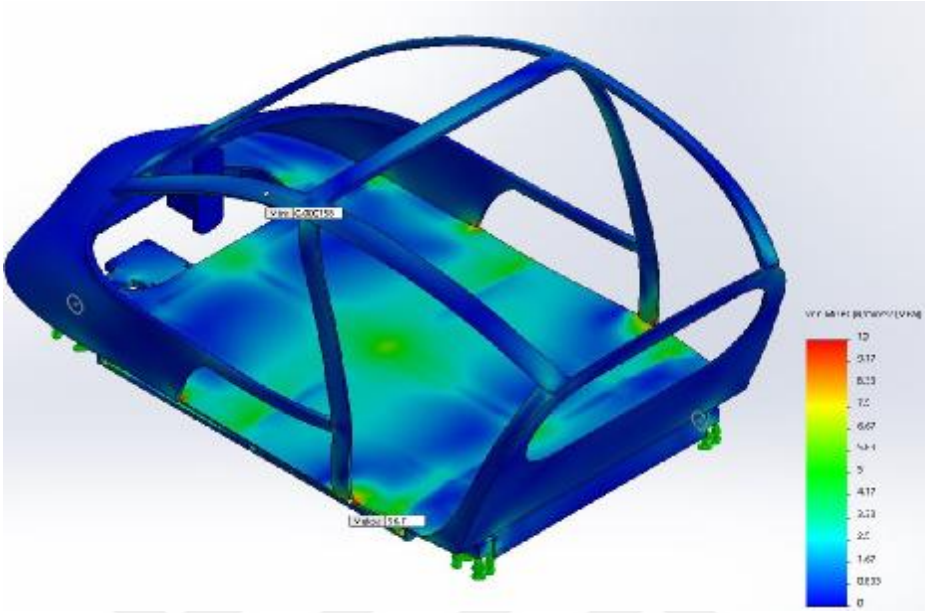

Figure 5.7. Von-Mises stress of the chassis

From Figure 5.7 it can be inferred that

Maximum Equivalent stress = 56.7 Mpa

Minimum Equivalent stress = 0.000158 Mpa

Results showed that maximum von-Mises stress of the design is 56.7 MPa and the value is far below the material's yield strength of 172 MPa. Maximum Von-Mises stress point as shown in Figure 5.7.

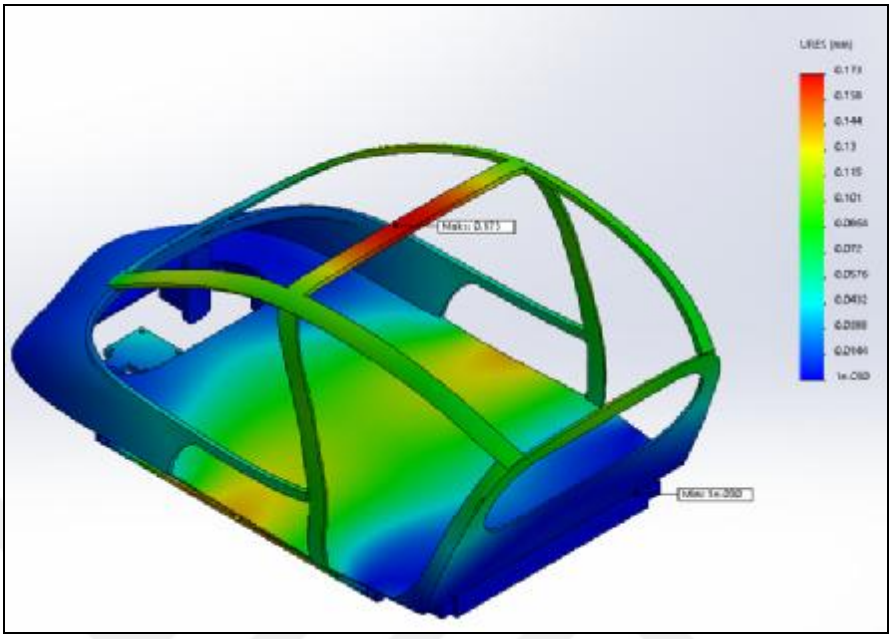

Figure 5.8. Total deformations of chassis

Maximum deformation = 0.173mm

Minimum deformation = 1e-030 mm

Maximum deformation was observed in the center of roof pillar.

5.2. Discussion of Results

Maximum stresses and deformations are given in Table 5.2 according to versions.

Table 5.2. Maximum stress, deformation and weight of the chassis due to versions

Chassis	**Version 0**	**Version 1**	**Version 2**	**Version 3**
Monocoque	Carbon fiber	AL6061	AL6061	ST-37
Platform	AL6061	ST-37	AL6061	ST-37
Maximum Deformation(mm)	0,07	0,17	0,35	0,17
Maximum Stress (Mpa)	23,1	21,6	30,6	56,7
Total Chassis Weight (Kg)	233,3	491,7	298,0	776,0

According to Table 5.2, minimum value of maximum deformation is observed in version 0, minimum value of maximum stress is observed in version 0 and version 1, and minimum value of total chassis weight is observed in version 0. According to tables version 0 has the most effective chassis due to stress, deformation and wieght. These results prove that hybrid chassis (monocoque is carbon fiber and platform is AL6061) which is designed for study has a great value both light weight and deformation/stress.

5.3. EV Range Calculation

In order to calculate range of the EV, matlab/simulink software was is used. The simulation details are provided below.

5.3.1. Electrical Vehicle Range Simulation

5.3.1.1. Simulink Parameters

```
% Vehicle model parameter setup
eta   = 0.7;    % efficiency
rw    = 0.273;  % tire radius, m
itran = 0.3;    % transmission gear ratio
mv    = 677;    % Vehicle mass, kg (This value changes for versions)
                % mv = 677; % kg for version zero
                % mv = 936; % kg for version 1
                % mv = 742; % kg for version 2
                % mv = 1220; % kg for version 3
Af    = 2;      % m^2 frontal area
Cd    = 0.25;   % drag coefficient
T     = 42.38;  % motor output tork
tf    = (352 / 170)*3600; % simulation time in seconds

% Fixed settings
vo    = 0;     % wind speed
rho   = 1.293; % kg/m^3 density of air
urr   = 0.015; % rolling force coefficient
g     = 9.81;  % gravitational acceleration
alpha = 0;     % slope angle
```

In the above listed code, the simulation initiliasation parameters are presented. The code shows the parameter values and variation of mass of the chassis for the simulations performed. In Figure 5.9 system model is shown.

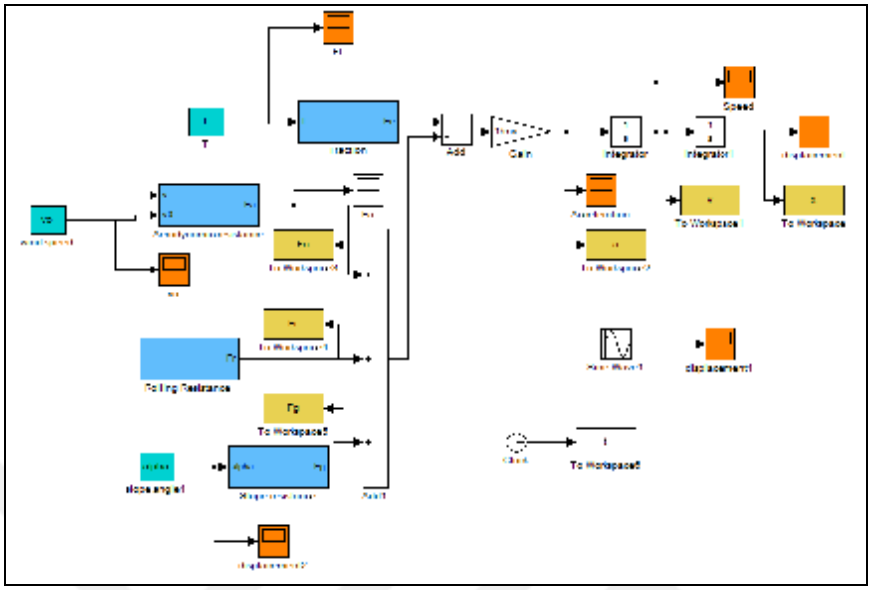

Figure 5.9. Simulink model range calculation of EV

5.4. The studied versions of the chassis for weight optimisation

In the following part of the study, four different types of chassis is studied. The types are presented in Table 5.3 below. It is shown with the study that the total weight of the chassis plays an important role in range determination of the vehicle. The below versions corresponde to different chassis compostions. Each chassis is studied and simulated indivudually.

Table 5.3. The studied versions of the chassis for weight optimisation

Chassis	Version 0	Version 1	Version2	Version3
Monocoque (top)	Carbon Fibre	AL6061	AL6061	ST-37
	85. kg	150.5 kg.	150.5 kg.	434.7 kg..
Platform (bottom)	AL6061	ST-37	AL6061	ST-37
	147.5 kg	341.3 kg	147,50 kg	341.3 kg
Weight of the platform	233,327 kg	491,742 kg	297,977 kg	775,976 kg

In the following part of the thesis, the chassis versions studied are presented with simulation results.

5.4.1. Simulation study for Version 0

In this study, proposed chassis design is presented. The mass of the chassis is 677 kg and the vehicle range is found to be around 211,01 km. In Figure 5.10 below, the parameters of the vehicle motion is presented. In the Figure 5.11, the forces generated during the simulation is presented.

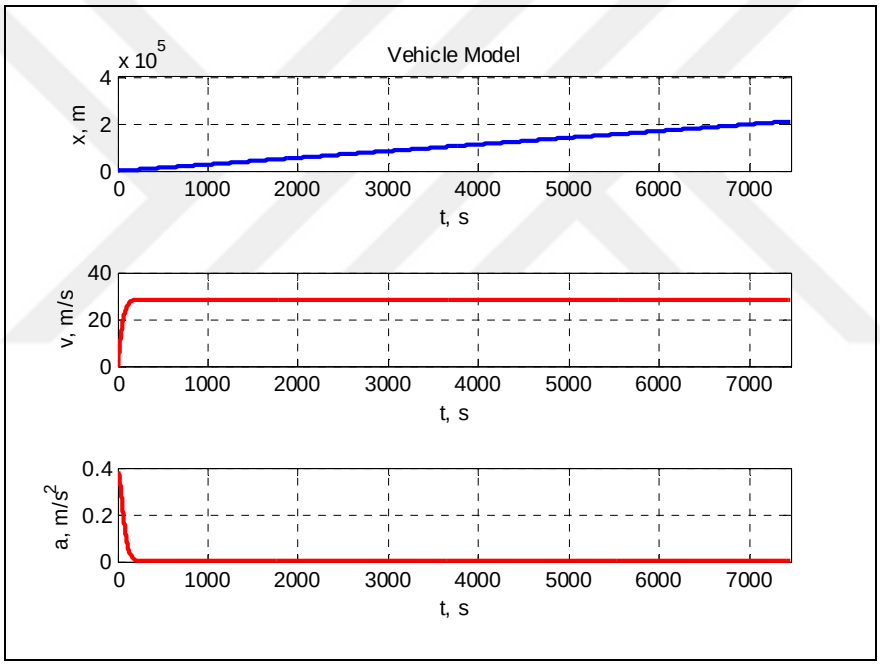

Figure 5.10. Motion results for version 0 chassis

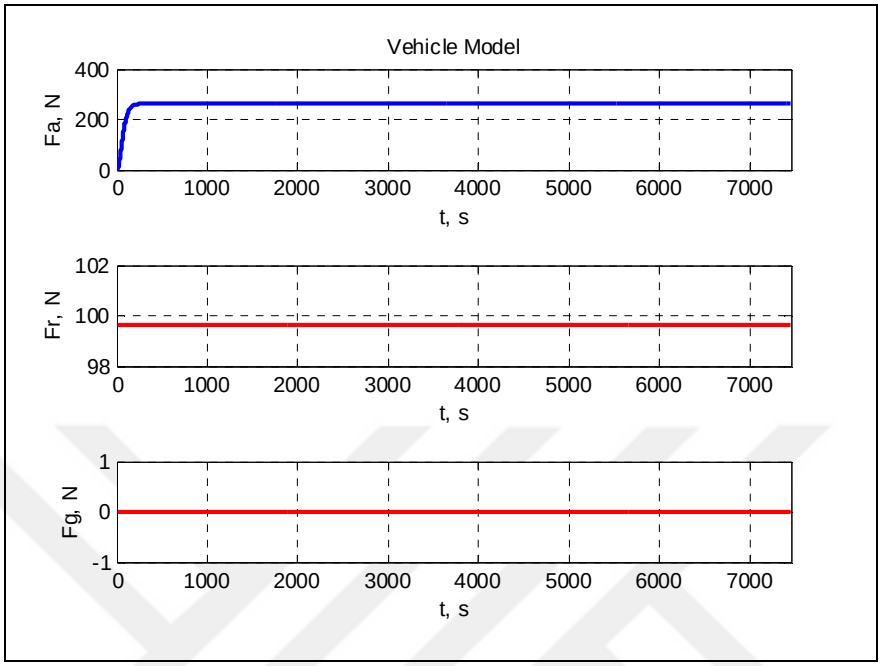

Figure 5.11. The forces generated during the study for version 0 chassis

5.4.2. Simulation study for Version 1

In this study, version 1 type chassis design is presented. The mass of the chassis is 936 kg and the vehicle range is found to be around 194,43 km. In Figure 5.12 below, the parameters of the vehicle motion is presented. In the Figure 5.13, the forces generated during the simulation is presented.

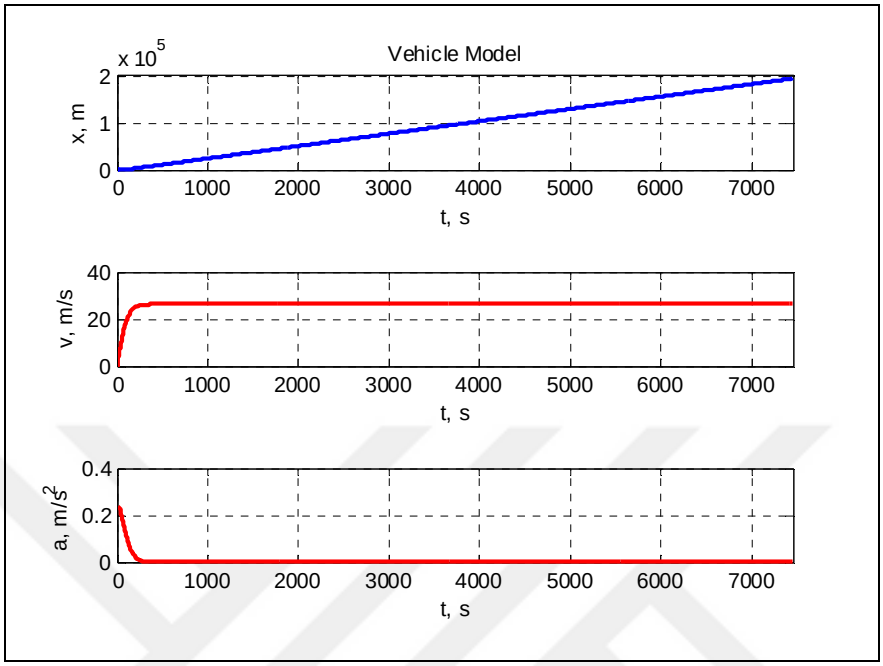

Figure 5.12. Motion results for version 1 chassis

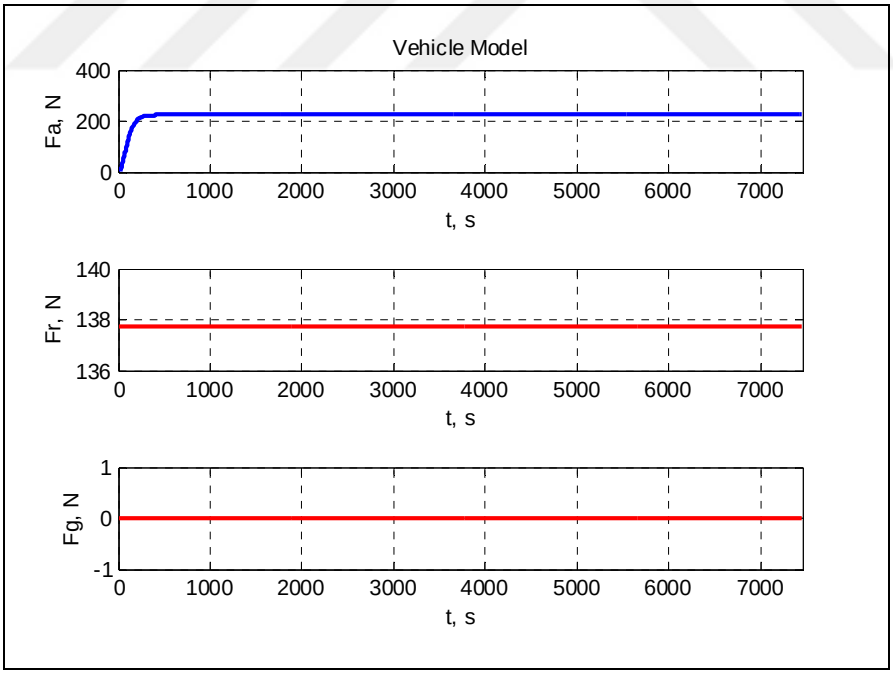

Figure 5.13. The forces generated during the study for version 1 chassis

5.4.3. Simulation study for Version 2

In this study, version 2 type chassis design is presented. The mass of the chassis is 742 kg and the vehicle range is found to be around 206,96 km. In Figure 5.14 below, the parameters of the vehicle motion is presented. In the Figure 5.15, the forces generated during the simulation is presented.

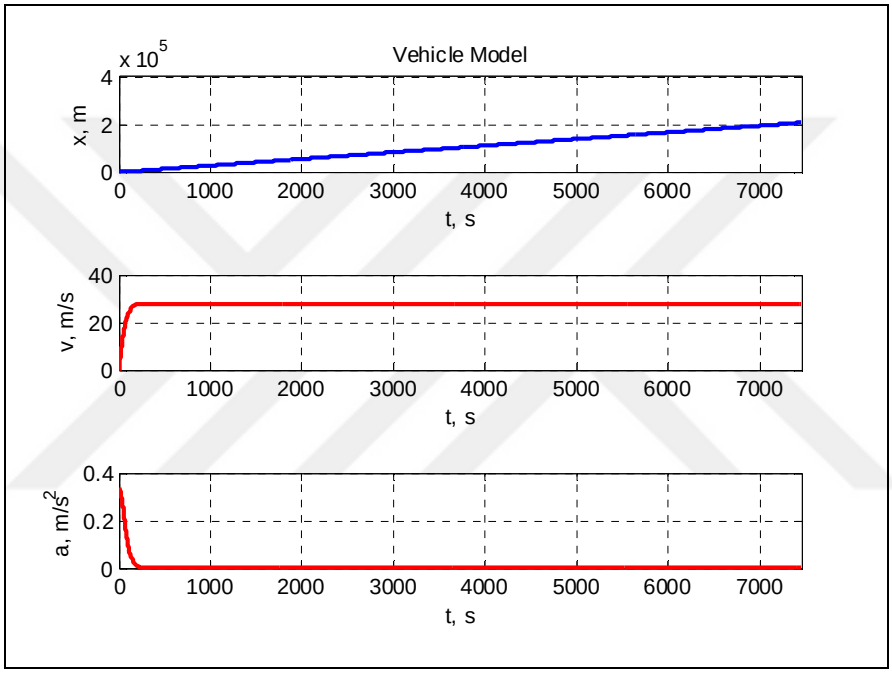

Figure 5.14. Motion results for version 2 chassis

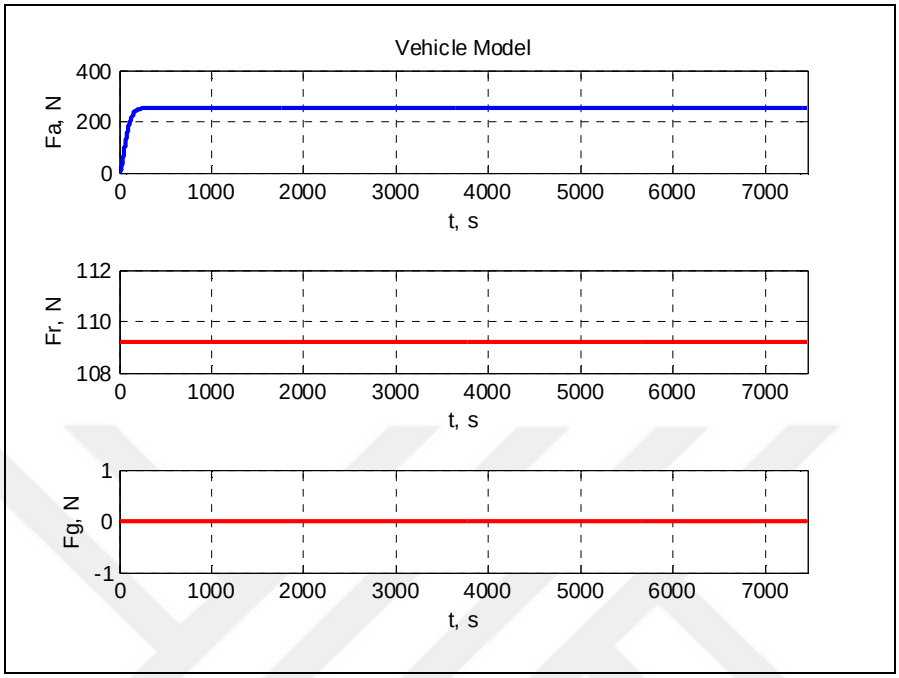

Figure 5.15. The forces generated during the study for version 2 chassis

5.4.4. Simulation study for Version 2

In this study, version 2 type chassis design is presented. The mass of the chassis is 1220 kg and the vehicle range is found to be around 174,60 km. In Figure 5.16 below, the parameters of the vehicle motion is presented. In the Figure 5.17 the forces generated during the simulation is presented.

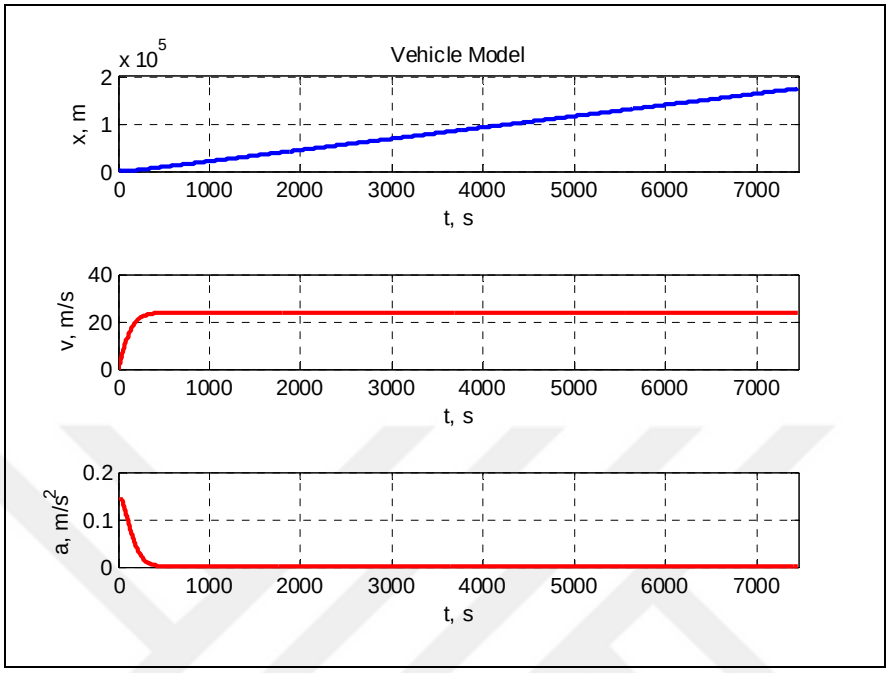

Figure 5.16. Motion results for version 3 chassis

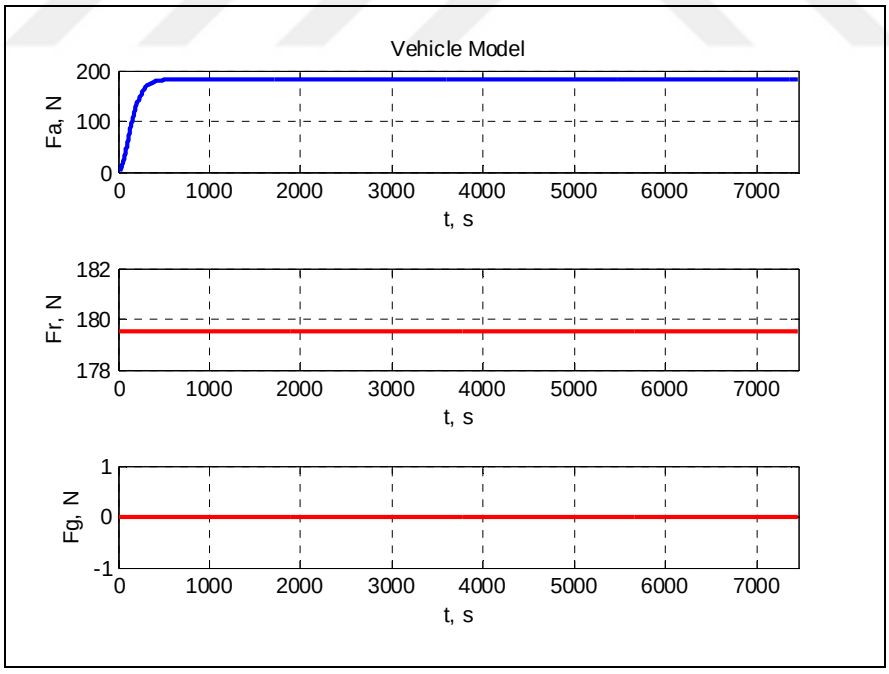

Figure 5.17. The forces generated during the study for version 3 chassis

It can be seen from Table 5.4 that the chassis versions studied have different range performances. The proposed chassis appears to provide about % 20 additional range compared to version 3 which corresponds to all steel type of chassis. Therefore, it is very much clear that a composite chassis is an advantage in terms of vehicle range especially for electric cars where energy storage is a main technical problem limiting the range of the vehicle.

Table 5.4. The studied versions of the chassis types and their range study results

Chassis	**Version 0**	**Version 1**	**Version2**	**Version3**
Monocoque (top)	Carbon Fibre	AL6061	AL6061	ST-37
	85.8 kg	150,5 kg	150.5 kg	434.7 kg
Platform (bottom)	AL6061	ST-37	AL6061	ST-37
	147.5 kg	341.3 kg	147,5 kg	341.3 kg
Weight of the platform	233.3 kg	491,7 kg	297,9 kg	775,9 kg
Total weight of vehicle	677 kg	936 kg	742 kg	1220 kg
Range of Vehicle	211.01 km	194.43 km	206.96 km	174.60 km
% Advantage	120,85	111,36	118,53	100
Additional % advantage gained	**20,85**	**11,36**	**18,53**	**1**

6.CONCLUSION

The primary objective of this work was to extend the range of the electric vehicle. In order to achieve this, the size and weight of the vehicle was reduced, instead of traditional materials, very light and durable materials were used for designing of EV to reduce the weight of the vehicle. In addition, the choice of battery and mPotor was made in accordance with technological developments. Especially battery carrier systems designed not to adversely affect the center of gravity of the vehicle. Then, appropriate mechanisms have been designed on the chassis to enable rapid battery replacement in the event of vehicle battery discharges.

In order to design and analyze all components Catia software was used. The designs were sometimes modified or improved according to the analysis results. The modifications were continued until the most appropriate design was achieved. The analysis results of the vehicle design were quite satisfactory.

After the design work was done, the range calculation was made. Matlab / simulink program was used to determine range distance. For the Matlab/Simulink study 4 different chassis types with different compositions are generated. The version 0 corresponds to proposed chassis while the version 3 corresponds to the conventional chassis. The presented simulation results indicate that the proposed chassis improves the performance of the conventional chassis by about %20. The achieved range is 211,01 km.

The range of the vehicle has also proved to be better results than some of the range improvement results found in other studies. However, battery and motor technologies need to be further developed so that electric vehicles can be used as alternatives to internal combustion vehicles. It is absolutely necessary to increase the battery capacities and reduce the battery weights so that the vehicle range can be further improved.

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